SYSTEM OF

PHYSIOLOGIC THERAPEUTICS

VOLUME X

System of Physiologic Therapeutics

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A SYSTEM

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EDITED BY

SOLOMON SOLIS COHEN, A.M., M.D.

SENIOR ASSISTANT PROFESSOR OF CLINICAL MEDICINE IN JEFFERSON MEDICAL COLLEGE; PHYSICIAN TO JEFFERSON MEDICAL COLLEGE HOSPITAL, TO THE PHILADELPHIA HOSPITAL, AND TO THE RUSH HOSPITAL FOR CONSUMPTION, ETC.

VOLUME X

PNEUMOTHERAPY

INCLUDING

AËROTHERAPY

AND

INHALATION METHODS AND THERAPY

BY

DR. PAUL LOUIS TISSIER

ONE-TIME INTERNE OF THE PARIS HOSPITALS, ASSISTANT CONSULTING PHYSICIAN TO LAENNEC AND LARIBOISIERE HOSPITALS, CHIEF-OF-CLINIC IN THE FACULTY OF MEDICINE OF THE UNIVERSITY OF PARIS

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TO

Professor G. Hayem

MY BELOVED MASTER

PREFACE

While, in its broad outlines, the present volume follows the general plan of the System of which it is part, the critical reader will observe some important differences in matters of detail; these are purposive, for the better exposition of the subjects discussed.

In the first place, the history of the development of pneumotherapy and of its various methods receives much greater attention than has been given to history in the other volumes of the series. Secondly, the details of physiologic experiments—and, in Part II, of postmortem studies—by various observers, are given with considerable fullness. The reasons for setting forth these matters at length ought to be obvious. Aërotherapy is as yet far from being appreciated at its true worth by the majority of physicians, and information concerning its evolution and its basic facts is much less general than is the corresponding knowledge in relation to other branches of physiologic therapeutics—mechanotherapy or hydrotherapy, for example. Furthermore, the conclusions of experimenters as to the physiologic and pathogenetic effects and the therapeutic application of condensed air and rarefied air—whether in caissons or pneumatic chambers, in balloon-voyages or mountain-ascensions, during sojourn at altitudes, or when various forms of differential apparatus are utilized—are not entirely concordant; and to have set forth dogmatically the views of author or editor without full statement and fair examination of discrepant opinions could scarcely have been satisfactory. Nevertheless, the reader is not left in doubt amid a multitude of conflicting assertions and antagonistic recommendations. In many instances the author has succeeded in reconciling observations apparently contradictory, by pointing out the diverse conditions under which they were made and suggesting the necessary corrections in the results; in others, either through original studies or by carefully analyzing the published records and comparing them with established data of physical and biologic science, he has—in the editor's deliberate judgment—correctly settled the disputed points; while in every instance he has given a clear and definite opinion. It is therefore hoped that this

thorough and judicial presentation of facts will contribute to the greater vogue of the highly important therapeutic measures under consideration.

A third particular in which the present volume differs from its companions, is the attention given in Part II—on Inhalation Methods—to certain aspects of pharmacology. In the consideration of mineral waters, it is true, a study was necessarily made of the physiologic and therapeutic action of their chemical constituents; in this volume, however, the deliberate addition to air and to watery vapor of medicinal substances—drugs—not found therein in nature, is described, and, under certain conditions, counseled. It cannot be denied that this constitutes a departure from the strict letter of our sub-title; but, as stated in the editor's Foreword to the System, the advocacy of physiologic therapy is not intended to antagonize discriminating pharmacotherapy. Both are needed, but the former is too much neglected and demands a propaganda. Moreover, there is quite an intimate connection between the main topics of the book and its very limited digression into pharmacology. Modification of the atmosphere by increasing or diminishing the proportion of one of its normal constituents—oxygen, nitrogen, carbon dioxid, or watery vapor—is logically followed by the introduction of other gases into the respiratory medium; the inspiration in nature of the balsamic and terebinthinate emanations of pine forests can scarcely be separated from the medicinal inhalations of these and cognate vapors; while the study of the atomization of mineral waters at their source leads directly to atomization in general. Nevertheless—except in important instances, such, for example, as oxygen and sulphur—the mere pharmacologic study has been condensed and minimized; the greater share of attention being given to methods of preparation and administration and to the exposition of the conditions under which medicinal inhalations may prove useful.

A fourth departure from the arrangement followed in the volumes hitherto issued is the consideration, in immediate connection with each of the methods discussed, of its special therapeutics, instead of devoting a third part to this subject exclusively. Each plan has certain advantages; but in the present instance it is believed that the balance of usefulness inclines to the one adopted, especially as the full index gives complete and ready reference to all the methods advised in the treatment of any special affection.

As hydrotherapy is best understood and has received its highest development near Vienna, and as the rest-cure and the optical treatment of ocular defects with their far-reaching consequences are essentially the triumphs of medical Philadelphia, so may Paris be considered the

center of modern pneumotherapy. In pursuance of the aim of the System to have each therapeutic method elucidated by one whose training and experience have best fitted him for the task, this book has been written by a French clinician. Dr. Tissier's manuscript has been translated in part by Dr. Augustus A. Eshner, in part by Dr. Walter M. Brickner, of New York, and in part by Dr. R. Max Goepp, of Philadelphia, who has also prepared the index and assisted in revising the proof.

Bibliographic details have been omitted purposely; but, as in the other volumes, due credit has been given in the text to writers and experimenters quoted; the author having made free use of all trustworthy published material accessible, whether in monographs, journal reports, theses, or treatises—among the latter, especially the classic works of J. Solis-Cohen, M. J. Oertel, Paul Bert, and J. Carvallo.

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PART I

AËROTHERAPY

CHAPTER I

AIR AS A THERAPEUTIC AGENT; PNEUMATOMETRY AND SPIROMETRY

General Historical Review. Air as a Therapeutic Agent—Physical and Chemical Properties of Air. Physiologic Relations of the Atmosphere—Respiration; Cutaneous Respiration. Pneumatometry and Spirometry—Apparatus; Diagnostic Possibilities. Aërotherapeutic Methods—Open-air Treatment of Pulmonary Tuberculosis.

The term **pneumotherapy** is applied to the use of respired gases for therapeutic purposes, directly or as carriers of medicinal agents; **aerotherapy** is a branch of pneumotherapy, dealing with atmospheric air. These general definitions will need limitation, else the study of pneumotherapy would include certain subjects treated in other volumes of this series under the head of "Climatotherapy." Nevertheless it seems indispensable to begin by taking a broad view of the therapeutic employment of air, both to limit the scope of the procedures that will be studied in detail and to show their special value in the treatment of certain conditions.

General Historical Review

The idea of using air as a therapeutic agent, or, in other words, the first recognition of the objects of pneumotherapy, is ancient, but practical devices for the purpose are comparatively recent. Before reviewing briefly the principal stages of this form of therapy and giving credit to

the originators and propagators of special aërotherapeutic procedures, it may not be without interest to inquire into the reasons why the physiologic and pharmacologic study of air was neglected for so many centuries. These reasons appear to be of a general character, and to understand them we must review the history of the evolution of medical doctrines. The beneficent and sometimes curative action of air, viewed synthetically, was appreciated in the treatises of Hippocrates, but never given its deserved systematic study until the subject was taken up by modern investigators. The doctrines of Galen that held tyrannical sway over medical science during many centuries, and his narrow and misleading conception of conditions during health and conditions during disease,—which, indeed, have not ceased to reëcho on every page of many contemporary books,—are chiefly responsible for the long neglect of the precious resources afforded by the rational use in medicine of the forces of the universal environment. Although great teachers did not fail in every generation to point out the true path of a rational therapy, theirs were but a few strong, clear voices, lost amid a babel of unreason. Thus, it was not until the nineteenth century that the accepted science of medicine, renouncing metaphysical theories and returning to the great principles that form the basis of the Hippocratic doctrine, substituted observation, analysis, and experiment for the shifting systems of abstract speculation and scholastic logic.

This renascence, the significance of which becomes more and more manifest as time goes on,—and to which we owe antisepsis, asepsis, better methods of treating infectious diseases, and other innovations,—was not the work of a day. It began with the introduction of a scientific spirit into the study of medicine, and it is not too much to say that aërotherapy was one of its first achievements. When the doctrine of a natural tendency toward recovery inherent in an organism had been proclaimed once more, and Hippocratic or scientific medicine—for the terms are synonymous—had demonstrated that many of the symptoms observed in disease must be regarded as expressions of a defensive reaction, the great importance of so-called hygienic methods of treatment—dietetics, balneotherapy, climatotherapy and the like—quickly became manifest.

The most ancient medical book on the therapeutic action of air of which we have any knowledge, the "Treatise on Air, Mineral Waters, and Places," is conceived in the same spirit. Although it is not certain that the book was written by Hippocrates himself, yet it undoubtedly voices the doctrines of his school. The rôle attributed to the air in the physical and physiologic systems of the ancients was unquestionably great (Empedocles). Some authorities, like Anaximenes of Miletus,

even assigned to it the most prominent place; but it must be admitted that they dealt more in speculative contemplation, in unfounded hypotheses, in *à priori* conceptions, than in demonstrated facts. Hardly more than a few of the physical properties of air, particularly its elasticity, were known (Heron). Since that time the idea of elasticity has dominated all the ingenious applications of air that are described in the treatises on physics.

To return to the domain of medicine it should be remembered that the Greeks, and later the Arabs and the entire medical world of the Middle Ages, regarded changes in the air as the principal agents in the genesis and spread of epidemic diseases. It was not until the seventeenth century that the first exact data in regard to the composition and the physical properties of the atmosphere were acquired. Van Helmont, who was the first to use the word 'gas,' devoted particular attention to the study of carbon dioxid—a substance that Roger Bacon had known vaguely—and gave to it the name of '*gaz silvestre*.' He recognized its true origin and defined its principal characteristics. The acuteness and truly scientific quality of his mind are shown by the fact that he attributed to carbonic acid gas the accidents that arise from prolonged exposure in mines, and in cellars where grapes are undergoing fermentation. J. Black, in 1757, confirmed the discoveries of Van Helmont. Rey, in 1777, positively attributed the increase in weight of oxidized steel to the fact that air had entered into permanent composition with the metal. Paracelsus had already advanced this opinion, but merely as a hypothesis. About the same period Rey was demonstrating by actual measurement that air is a ponderable body, a fact which until that time had been denied, because, as he said, applying to gases the principle of Archimedes, "air was weighed in air." It must, however, be stated that Aristotle knew that a bladder filled with air was heavier than an empty bladder. Galileo, Toricelli, and Pascal definitely demonstrated the pressure of the atmosphere, and at the same time devised a practical, simple, and trustworthy method of measuring that pressure The study of the laws governing the elasticity of gases, promulgated by Boyle and Mariotte, and the investigation of the significance of variations in temperature, complete our knowledge of the physical properties of the air. After the works of Van Helmont and Rey had appeared, researches into the chemical composition of the atmosphere were made by Henshaw and Mayow, who described a vital igniting spirit or principle in air, which, they believed, kept alive a flame by means of combustion, and maintained life by means of respiration. But the problem of the composition of air cannot be regarded as having been solved before the publication of

the works of Hales, of Black, of Priestley, of Scheele, of Cavendish, and especially of Lavoisier (1775). The discoveries made since that time merely confirm or define the data already acquired, so that nothing remains but to collect a few fragmentary discoveries, which will be mentioned in their appropriate places in the course of this work.

Space forbids the attempt to do justice to the discoveries of Lavoisier, who completely overthrew the ancient doctrines, particularly the dogma of the four elements, and once for all assigned to biology its proper place among sciences, after establishing it on a firm basis by defining its fundamental laws. It is not too much to say that the work of Lavoisier not only dominates the particular question now under discussion as well as the entire subject of physiology and chemistry, but that it marks an epoch in the development of the scientific spirit of inquiry, and indeed of the human mind itself. The physiologist, the pharmacologist, and the practising physician thus came into possession of the necessary information to enable them to approach with profit the scientific study of the air considered as a therapeutic agent.

AIR CONSIDERED AS A THERAPEUTIC AGENT

Atmospheric air has been employed as a therapeutic agent in a great variety of conditions, and it would be impossible to give a complete historical review even of the applications of compressed and rarefied air alone, although that would by no means cover the entire domain of aërotherapy. For this reason a subdivision of the subject appears preferable, and we have now arrived at the point where the general plan of this book may be outlined.

It appears both simple and rational to treat air like any other agent that is to be studied from a therapeutic viewpoint—accordingly, under the following heads:

1. Its **physical** and **chemical** properties.
2. Its **pharmacologic** and **pharmacodynamic** possibilities; that is to say, the **methods** of its employment and their **effects** upon the organism.
3. Its **therapeutic** applications.

PHYSICAL AND CHEMICAL PROPERTIES OF AIR

The physical qualities and the chemical composition of the atmosphere are anything but constant; they vary with altitude, temperature, meteorologic conditions, and other factors. These variations and their causes will be discussed more at length in a subsequent connection; the briefest exposition of the most important characteristics of the air, em-

phasizing those more particularly concerned in aërotherapeutic procedures, will suffice for the present.

Constituents of Air

Air is a gaseous mixture composed principally of **oxygen** and **nitrogen** in proportions that were accurately demonstrated by Lavoisier in 1775. Later calculations by Gay-Lussac, Humboldt, Dumas, and Boussingault have necessitated very slight changes in Lavoisier's figures. According to the recent analyses of M. Leduc, air contains 23.20 parts of oxygen and 75.50 parts of nitrogen by weight; or 21.0 parts of oxygen and 78.06 parts of nitrogen by volume. A comparison of numerous analyses, contributed by a number of different chemists in all parts of the world, shows, according to Gavarret, that the proportion of oxygen in 10,000 parts of air by weight varies between 2258 and 2314. The lowest figure was obtained by Loewy in 1851 from a specimen of air taken over the North Sea. The highest figures were obtained at Brussels by Stas, and at Guadaloupe by Loewy. The proportion of oxygen in 10,000 parts of air by volume varies between 2038.8 and 2120. The lowest figure was obtained on the Ganges in 1849; the highest in Paris by Doyère in 1848.

As regards the **nitrogen** contained in the atmosphere, the recent researches of Ramsay and Lord Rayleigh show that a distinction must be made between nitrogen and another gas which had not been differentiated up to that time, and to which the name of **argon** has been given. Argon differs from nitrogen in being more soluble in water, in having a higher boiling-point (187° instead of 194° C.), by the fact that its spectroscopic lines differ from those of nitrogen, and finally by the peculiarity that it does not combine with any substance whatsoever. The air contains 0.937 per cent. of argon, which is not far from 1 per cent. of the atmospheric nitrogen. Schloesing and Regnard estimate the quantity of argon that dissolves in the blood as 0.4 in 10 parts by weight. It may be that argon is to some extent responsible for certain phenomena observed in individuals working in compressed air, especially the accidents that sometimes occur under those circumstances when a sudden rarefaction of the air takes place. **Helium, krypton, xenon,** and **neon** (Ramsay and Travers) deserve a passing mention.

In addition to oxygen and nitrogen, air contains a variable quantity of **carbon dioxid,** estimated at from 4 to 5 parts in 10,000 by volume. It is a remarkable fact that although carbon dioxid production is greatly increased in certain media, its proportion in the air varies very little.

According to the calculations of Boussingault, made about fifty years ago, the city of Paris produces 2,944,600 cubic meters of carbonic acid gas in a day; but in spite of this fact, if the amount of carbon dioxid present in the air in Paris during the daytime is represented by 100, the number 92 will be found to correspond to the proportion of carbonic acid gas several leagues from the city in the open country.

It has been found that 100 cubic meters of air contain of carbonic acid gas:

At Cape Horn (Hayden),	23.1 to 28.5 liters
At Santa Cruz,	26.6 liters
In Chile,	27 liters
At Martinique,	28 liters
In Paris (Dumas),	28 to 35 liters
In Florida,	29.2 liters
In Austria,	34.3 liters
In Lybia,	44 to 49 liters

In addition, the proportion of carbon dioxid varies in the same locality under different conditions; thus, it is higher during the night than during the day, and less after a rain. It will be seen later that a very slight increase in the proportion of carbon dioxid suffices to modify the pulmonary exhalations quite materially.

The amount of **ozone** (allotropic oxygen) in the atmosphere of populous places is practically negligible. On the average, the proportion is 0.001 in 100 cubic meters of air; the maximum being 0.0035. It sinks almost to zero in cities, as ozone is destroyed in the oxidation of the volatile principles present in the air where large numbers of animals or men are congregated (Schoenbein). At Montsouris, situated south of Paris, there is less ozone in the air when the wind is blowing from the north or northwest and has just come through Paris, than when a southerly or southeasterly wind prevails. The climatotherapeutic value of certain regions where coniferous forests exist is attributed in part to the presence of ozone in the atmosphere in decided quantities; whether by direct action, or indirectly through conservation of the purity of the air.

Of the other components of the air, there should be mentioned **ammonium nitrate** (Schloesing), **iodin, helium,** and organic and inorganic atmospheric **dusts.** M. Miquel has devoted a number of years to the task of making an accurate estimate of the number of varieties of organic dust in the atmosphere. Without entering into the details of the subject, it

may be said that the number of these dusts increases near the surface of the ground; that it is greater in periods of drought, and that it is always more considerable where large numbers of people are gathered. This question of impurities in the air, which has such a vital bearing on the subject of climatotherapy,* need not detain us further for the present.

There still remains one component of the atmosphere to be discussed. It is a very important one—namely, **aqueous vapor** (humidity). It is much more variable than the other constituents mentioned, the variations depending on temperature, altitude, geographic situation, and meteorologic conditions. The subject is treated fully in volume III of this series (pp. 32 to 38).

The Physical Properties of Air

These may be dismissed with a few words. Atmospheric air forms a continuous, transparent, slightly bluish layer, surrounding the terrestrial globe; it is elastic and compressible; its density diminishes in direct proportion with the distance from the ground; its weight is measured by the barometric pressure, which will be studied at length because a certain number of aërotherapeutic methods are based on the variations of the barometric column. Incidentally it may be mentioned that the mean **pressure** at sea-level is 76 centimeters (about 30 inches) of mercury.

PHYSIOLOGIC RELATIONS OF THE ATMOSPHERE

Respiration

Atmospheric air is normally in contact (1) with the **outer integument,** and (2) with the surface of the **respiratory organs.** Upon both it acts **mechanically** by virtue of its volume and weight, and the consequent equilibrium or want of equilibrium between the internal and external **pressure.** This subject will be referred to later in some detail. It acts also by means of its **chemical** properties, giving up **oxygen** to the blood and taking from the latter **carbon dioxid** and other waste products.

Other organs, especially the **stomach** and digestive tract, always contain a certain quantity of air introduced during deglutition. Is there, then, true gastric respiration? Yes, if by respiration be understood the absorption of oxygen; for it has been demonstrated that oxygen disappears rapidly from the closed intestinal canal. If a loop of intestine be isolated and oxygen be injected into it, the latter will soon be found to have been displaced by carbon dioxid. *Lobitis fossilis*, a creature that

* See volume III, pp. 21 *et seq.*

inhabits swamps, is said to breathe slowly through its intestine by swallowing free bubbles of air, which in their passage through the digestive tract undergo changes that can be determined by the composition of the air escaping from the anus. In man the importance of this form of respiration is so slight as to be negligible, although the functional significance of the air in the stomach, and the modifications it undergoes, have never been sufficiently studied. It may be said, however, that in certain individuals of the human species, the phenomenon in question has been observed; in hysteria particularly the deglutition of air assumes such an important rôle as to become a morbid symptom—aërophagia; but the only disturbances observed in such cases have been purely mechanical in origin.

Cutaneous Respiration.—Lavoisier, and later Seguin, experimented with a view to determining the part performed by **the skin** in the interchange of substances with the atmosphere. They placed their subject in a closed chamber, leaving his respiratory organs in communication with the external air. Regnault and Reiset experimented with a dog, a rabbit, and a hen, shut up in an impermeable sack filled with air. According to these authors, the quantity of carbon dioxid eliminated in twenty-four hours through the air-passages and through the skin is as follows: A dog weighing 7.159 kilograms eliminated through the skin 0.458 gram, and through the lungs 119 grams, of carbon dioxid. A rabbit weighing 2.425 kilograms eliminated 0.833 gram through the skin and 59.177 grams through the lungs. A hen weighing 1.940 kilograms eliminated 0.553 gram through the skin and 51.813 grams through the lungs.

The quantity of carbon dioxid eliminated through the skin increases under the influence of light, digestion, animal food, elevation of temperature, and especially exercise (Auber and Lange). Scharling and Hanover, by means of numerous experiments, determined more precisely the intensity of the gaseous interchange that takes place through the skin between the atmosphere and the blood in the subcutaneous capillary network. Comparing with the pulmonary interchange of gases that of the skin, the following results were obtained; the figures indicating the quantity of carbon dioxid eliminated in twenty-four hours:

	WEIGHT	CO_2 ELIMINATED THROUGH THE LUNGS	CO_2 ELIMINATED THROUGH THE SKIN
Boy of 12 years	22 kilograms	488.16 grams	4.34 grams
Girl " 11 "	23 "	459.84 "	2.97 "
Man " 28 "	82 "	878.88 "	8.95 "

There is no doubt, therefore, that the skin is permeable for the gases

contained in the external atmosphere, whenever these acquire sufficient tension (Gerlach), but it has been impossible to find record of any exact research concerning the ultimate effect on the cutaneous gaseous exchange of variations in the atmospheric pressure.

PNEUMATOMETRY AND SPIROMETRY

Within the lungs the physiologic action of the air can be exerted only by virtue of the series of mechanical acts by which the air is brought from the exterior through the air-passages down to the surface of the pulmonary epithelium, and by which the gaseous contents of the alveoli are again expelled. A knowledge of the forces concerned in inspiration and expiration, and of the quantity of air taken into the lungs and exhaled, is therefore of prime importance in the application of aërotherapeutic measures, which have for their first object a modification of the pulmonary ventilation. It is for this reason that attention will first of all be called to the various **pneumatometric** and **spirometric methods** of estimating the pressure and the volume of air within the lungs.

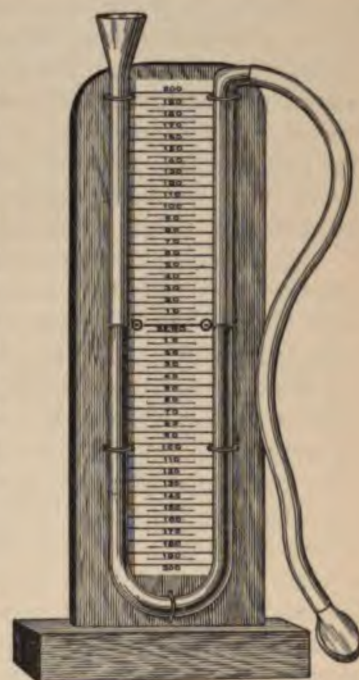

FIG. 1.—WALDENBURG'S PNEUMATOMETER.

PNEUMATOMETRY

Waldenburg, to whom must be accorded the merit of having made the most accurate and most extensive researches in the field of pneumatometry, used a special apparatus of very simple construction, based on the principle of the manometer. It has since been improved by Krauss, Mordhart, and Waldenburg himself. It is the same as that employed in connection with the aërotherapeutic apparatus that bears his name, and which will be described later. A U-shaped tube, open to the atmosphere and suitably mounted, is filled with mercury in both branches to the same level, which is marked zero. One branch is connected with a rubber tube and mouthpiece (or mask or nosepiece) used by the person under observation, whose expiratory and inspiratory force is measured by the

ascent or descent of the mercury in the other branch, as shown upon a millimetric scale (Fig. 1).

Marchal designed a complicated apparatus much used in France. The principal portion contains a circular manometric tube of metal, the extremities of which are connected by a special contrivance with the points of a quadrant, graduated in such a way that each division corresponds to one centimeter of mercury. This manometer communicates with the special mouthpiece through which inspiration or expiration is performed. A metallic reservoir which acts as a regulator is interposed between the manometer and the mouthpiece. By means of a system of stopcocks and valves the same apparatus can be used for both phases of respiration. The great disadvantage of this apparatus is the necessity of using a mouthpiece, consisting either of a mask or a simple tube, and the impossibility of excluding the action of the muscles of the lips and mouth. Another source of error resides in the fact that the results vary according as the movements of expiration or inspiration are performed slowly or rapidly.

The following figures are taken from Waldenburg: In slow respiration the effort made by a healthy male adult during inspiration is equivalent to from **100** to 120 millimeters of mercury; in the female, from **25** to 60 millimeters. The effort made during expiration under the same conditions is equivalent to from **50** to 150 millimeters in the male, and from **30** to 80 millimeters in the female. In forced respiration the respiratory effort is equivalent to from **80** to 160 millimeters in the male, and from **50** to 80 millimeters in the female; the expiratory effort is equivalent to from **80** to 130 millimeters in the male, and from **60** to 110 millimeters in the female. The figures in **antique type** represent the minima compatible with health. From these data, confirmed by the investigations of Biedert and Krause, it appears that the inspiratory is somewhat less than the expiratory force; according to Marchal, the proportion is as 2 to 3; according to Brünnecke, as 7 to 10. Krause observed a considerable difference in the figures obtained from the same individual according as a nasal tip, a mouthpiece, or a mask was used, which shows how much the muscular apparatus of the mouth is capable of modifying the measurements obtained. Waldenburg asserts that the pneumatometric method possesses some diagnostic value in pulmonary affections, but the variations in the figures, depending on the conditions of the experiments, and the actual difficulty of the technic, have so far prevented the general adoption of the method in practice. According to Brünnecke, it is not the absolute value of the inspiratory or expiratory effort, but the relation between the two, that is so remark-

ably constant under normal conditions. Whenever this relation is changed, it is usually the inspiratory effort that diminishes. Elsberg, of New York, however, laid great stress upon diminution of expiratory capacity as an early sign of pulmonary impairment.

Spirometry

Spirometry has for its object the measurement of the **vital** or **respiratory capacity.** It may be well at this point to recall that the term **tidal air** is used to designate the mean quantity of air inspired or expired at each respiratory movement under normal conditions; this quantity is 500 cubic centimeters (about 30 cubic inches). The term **reserve air** is applied to the (mean) quantity of air that can be expelled from the lungs by forced expiration at the end of an ordinary expiration; it is estimated at 1600 cubic

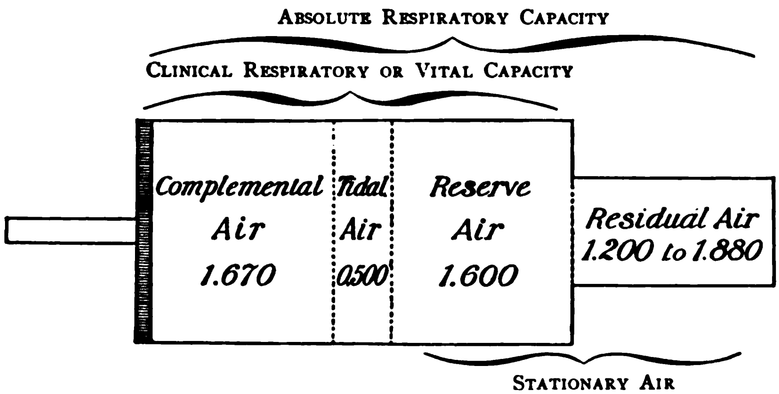

FIG. 2.—DIAGRAM ILLUSTRATING PULMONARY CAPACITY.

centimeters (say, 98 cubic inches). The term **complemental air** is applied to the (mean) quantity of air that can be drawn into the lungs by forced inspiration at the end of an ordinary inspiration; it is estimated at 1670 cubic centimeters (say 102 cubic inches). The term **residual air** designates the quantity of air remaining in the lungs even after the most forcible expiration of which the individual is capable; this is estimated at from 1200 to 1880 cubic centimeters (say 73 to 115 cubic inches). **Stationary air,** the volume remaining in the lungs after an ordinary expiration and equaling the sum of reserve and residual air, is variously estimated at from 2470 to 3440 cubic centimeters (150 to 210 cubic inches). The sum total of these components—complemental, tidal, and stationary air —gives the **absolute respiratory capacity,** the mean volume of which is found to be 5410 cubic centimeters (330 cubic inches) in a healthy male

adult of mean stature (5 feet 8 inches). In practice, however, the **term respiratory** or **vital capacity** is given, following Hutchinson, to the volume of air **expelled** by a forced expiration following a forced inspiration; or, in other words, to the sum of the tidal, complemental, and reserve air—omitting the residual air;—a volume which is estimated at 3770 cubic centimeters (230 cubic inches*) for the standard adult man. It is true that the volume of expired air compared with the volume of inspired air at the same temperature, both being dried, is as 99 to 100. In clinical examinations, however, owing to the higher temperature and to the presence of a greater proportion of aqueous vapor in expired air, the two volumes are practically equal.

Respiratory Capacity

The respiratory capacity is **determined** by special methods to be described later. These methods are important in the first place, because they furnish a means of measuring the effects of aërotherapeutic procedures as well as of establishing the indications for them, and in the second place, because the principle of a number of aërotherapeutic apparatus is exactly the same as that of the spirometer.

The **volume** of the respiratory capacity varies with the age and stature (Hutchinson, Wintrich). In a child of three years of mean stature it has been found to be 400 cubic centimeters (24.4 cubic inches); up to the age of twenty, and, according to some authors, up to the age of thirty or even thirty-five, the respiratory capacity increases steadily. The greatest augmentation occurs between the ages of fifteen and sixteen. Later a diminution takes place and progresses *pari passu* with the ossification of the costal cartilages. The vital capacity is considerably less in the female than in the male: 2500 cubic centimeters (152.5 cubic inches) in a healthy female adult of mean stature, as against 4700 cubic centimeters (286.7 cubic inches) in the male under like conditions. It has been established by the investigations of Hutchinson, Simon, Vierordt, and Arnold that the respiratory capacity is proportionate to the stature, the increase being, according to Vierordt, 60 cubic centimeters to every centimeter, or about 9 cubic inches to every inch, of height above the standard; while Hutchinson gives 8 cubic inches for the inch in height.

The problem of the **quantity** of **inspired** and **expired** air has been

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* In English works the figures usually given are: for a man of 5 feet 8 inches, *tidal air*, 20 cubic inches + *complemental air*, 110 cubic inches + *reserve air*, 100 cubic inches = 230 cubic inches, **vital capacity.** *Residual air* is estimated at 100 cubic inches. As a matter of fact, all these figures are, as regards any individual case, approximations only.

studied chiefly by English investigators. In 1679 Borelli made some investigations on this point which were repeated by Keill in 1708, by Halyck, by Jurine in 1772 and by Hales in 1773. Boerhaave measured the difference in the level of the water in his bath-tub during inspiration and during expiration; Lieberkühn, in 1740, measured the changes in the volume of the thorax during the two phases of respiration. Goodwin, Davy, Thomson, Kentish in 1814, and Kite collected the expired air under a bell-jar filled with water. This principle is applied in the pulmometer of Abernethy and in the pneumometer of Kentish. In 1846 Hutchinson taught the clinical importance of physiologic research and devised the instrument which bears his name. It consists virtually of a gasometer applied to the respiratory air-current. The same apparatus with a few trifling modifications has been used many times since by careful observers, among whom may be mentioned Simon, Fabius, Schneevogt, Wintrich, Arnold, C. W. Müller, and Waldenburg. The conclusions of Hutchinson have been modified but little. It is interesting to note in passing that the gasometer, which has become so useful in the arts in general, was invented by James Watt about 1790, to permit Thomas Beddoes to lay the foundations of pneumotherapy.

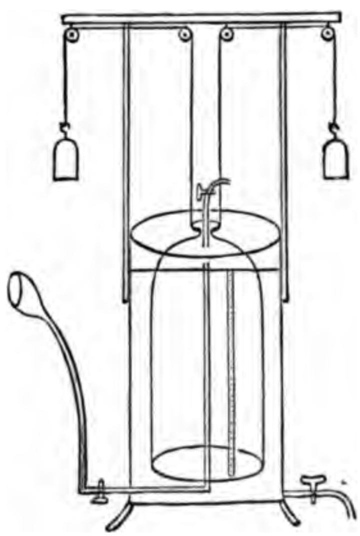

FIG. 3.—HUTCHINSON'S SPIROMETER.

Hutchinson's spirometer consists (1) of a cylindrical reservoir of sheet-iron about 0.45 meter high, which is filled with water and (2) a bell-jar immersed in the water and provided with a stopcock at its upper portion. The jar, hung in cords which pass over pulleys attached to two vertical supports, is counterbalanced by weights. The air, first expired through a mask applied to the patient's mouth, is conducted through an external rubber tube and then through a metallic tube in the interior of the reservoir to the upper portion of the bell-jar. As soon as expiration takes place, the air enters the jar and the latter rises. The distance traversed by the jar is read off on a graduated scale, and the volume of the expired air is then calculated. Hutchinson also devised **a portable spirometer** provided with a quadrant, in which the respira-

tory capacity is measured by the movement of a pointer. The instrument is contained in a wooden box shaped like a truncated quadrangular pyramid. Wintrich, in 1854, added a slight modification to Hutchinson's bell spirometer. In Wintrich's apparatus the jar is movable and is supported by a single rod. According to Hecht, from whom some of the information contained in this chapter has been borrowed, this instrument of Wintrich's appears to be one of the most accurate.

Spirometer of Schnepf.—In the apparatus devised by Schnepf in 1856 the bell-jar is attached to a chain, the links of which are of unequal lengths so as to compensate for the variations in the weight of the jar, according as it is immersed to a greater or lesser depth in the water of the reservoir. The accompanying schematic drawing is borrowed from Mathias Duval: V represents a pewter cylinder filled with water; T, T, respiratory tube provided with a mouthpiece, A; C, bell-jar of gasometer.

Boudin's Spirometer.—Boudin, in 1854, used an apparatus which is more remarkable for its convenience of application than for the accuracy of its results. A rubber bulb is attached by its lower surface to a hoop or ring made out of a strip of metal. At the top of the bulb is inserted a small graduated rod that passes through an opening in the upper portion of the hoop. When the bulb is empty, the zero mark on the graduated rod corresponds to the surface of the hoop. When the contents of the

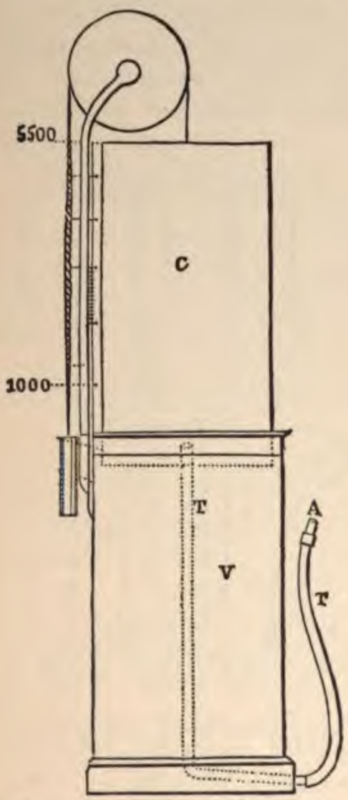

FIG. 4.—SPIROMETER OF SCHNEPF.

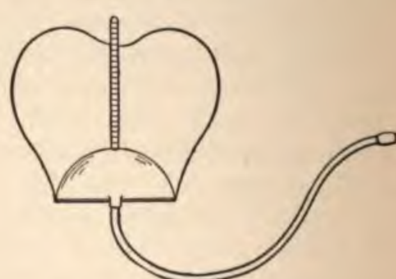
FIG. 5.—BOUDIN'S SPIROMETER.

lungs are expelled into the bulb through a tube, the graduated rod rises in proportion to the quantity of the expired air.

Bonnet's Apparatus.—Bonnet, of Lyons, in 1856, used an ordinary gas-meter for a spirometer. This apparatus, which he called a pneumatometer,—a word that ought not to be used in this connection, because it might give rise to confusion with pneumatometers properly so called and intended for the determination of respiratory pressure,—possessed the advantage that several measurements could be made in succession.

Guillet's Pneusimeter.—With the spiral pneusimeter of Guillet the expired air can be measured to within a deciliter. The instrument is easy to use. It consists of a horizontal cylindrical tube made of pewter and slightly incurved at its extremity. Within the cylinder is a spiral or turbine with very delicate wings which is put in motion by the expiratory air-current. The axis of the turbine projects from the cylinder and connects, by means of an endless screw, with an indicator on which the number of revolutions of the turbine, and therefore the volume of expired air, can be read off, the volume of air being practically proportionate to the number of turns of the screw.

Broca's pneumometer, devised in 1872, is constructed on the same principle as that of Boudin. The expired air is forced into a pair of bellows, the lower blade of which is fixed. The pressure of the air raises the upper blade of the bellows, and the length of the excursion is measured by means of a sliding indicator which records the quantity of the expired air.

Galante's spirometer is a modification of Broca's instrument.

Dupont's apparatus, which remains to be described, is the simplest by far. Although but approximately accurate, it has at least the advantage of being much more practical and of giving comparable results. It is composed of two cylindrical vessels capable of holding about four liters and connected at their lower extremities by a rubber tube. One of these vessels, which is graduated in cubic centimeters, is closed by a rubber stopper provided with a glass tube, which in turn is connected with a rubber tube and stopcock. The latter terminates in a mouthpiece in the form of a mask or a smaller tube, according as it is desired merely to apply it to, or to introduce it into, the mouth. The **technic** is as follows: The open vessel is filled with water and raised until the liquid in the closed vessel rises to the zero mark. The stopcock in the rubber tube is then closed, to prevent the liquid from flowing back into the open vessel. The mouthpiece is now applied to the mouth at the end of a forced inspiration, and, the stopcock having been opened, the air in the lungs is expelled through the rubber tube. At the end of the expiration

the stopcock is closed. The liquid is now brought to the same level in the two vessels by displacing them, and the height, which corresponds to the equalized level on the graduated vessel, indicates the volume of air expired at atmospheric pressure.

Approximately accurate and convenient for comparative clinical observations is the **dry spirometer** of Barnes (Fig. 6). Within a closed cylinder of metal is placed a rubber bag, which, when inflated, pushes up an index rod graduated to show cubic inches. The principle is the same as that of Boudin's instrument.

FIG. 6.—BARNES'S DRY SPIROMETER.

Graphic Methods

As the graphic method makes it possible to register the respiratory movements, the quantity of inspired and of expired air can be estimated indirectly by comparing the amplitude of the two respiratory phases. These procedures all require such delicacy of manipulation that they have rarely been performed outside of the laboratory (Vierordt and Ludwig, 1855; Marey, 1865 to 1878; Bergeon, 1869).

Bergeon-Kastus Anapneumograph.—The apparatus devised by Bergeon and Kastus was called by the inventors an anapneumograph. It consists of a sphygmograph after Marey, applied to the current of air which enters and escapes from the chest during each respiration, or, in other words, it practically consists of a spring applied to the inspiratory and expiratory air-currents. A recording lever armed with a stylus communicates by its other extremity, which is somewhat enlarged, with a tube through which respiration is performed. The enlarged portion, consisting of a very thin and very light piece of aluminum, is held immovable in a vertical position by means of two springs of equal power pressing in opposite directions. It acts as a valve, opening and shutting at each respiratory movement and carrying along with it the recording lever, which commits to paper, by means of vertical and horizontal

strokes, the movements of the valve; that is to say, the impressions which the valve as well as the spring receives from the currents of air. These impressions vary both in intensity and in duration. The exquisite sensitiveness of the apparatus, which registers the faintest movement of air, like the liberation of a bubble in a bottle, affords an accurate means of measuring the frequency of the respiratory movements, the relative duration of each movement, its intensity, and especially its form. The authors have thus succeeded in obtaining tracings characterized by a marvelous constancy, and varying in appearance according to the age of the subject and accordingly as the lungs were in a state of exaggerated movement or in a pathologic condition.*

Long and tedious as this preamble may appear, it is nevertheless as indispensable as a knowledge of the alphabet for one who wishes to learn to read; for since true science is based on observation, we must have instruments of mensuration with which to acquire the necessary data. The birth of chemistry was made possible by the invention of the balance, and in the same way an exact knowledge of the various aërotherapeutic methods requires familiarity with the principles and methods of pneumatic mensuration.

Measurement of Residual Air

Gréhant uses the term "capacity of the respiratory apparatus" to designate the quantity of air that remains in the lungs at the end of an ordinary expiration. This quantity is composed of the residual and the reserve air. The spirometer enables us to measure the air capacity in maximum ventilation of the lungs, consisting of the tidal, the reserve, and the complemental air; as well as to measure separately the tidal air, the reserve air, and the complemental air, but it does not enable us to measure the residual air alone.

Gréhant's Apparatus.—Gréhant resorted to the method of mixing hydrogen gas with air. His apparatus consists of a bell-jar capable of holding from 2 to 3 liters, inverted over a vessel full of water. The bell-jar contains exactly a liter of hydrogen. The top of the bell-jar communicates with a system of tubes provided with a three-way stopcock from which another tube runs to the mask. The stopcock enables the individual to breathe at will either in the air or in the bell-jar. Communication with the bell-jar is cut off exactly at the end of an ordinary expiration. After four or five respirations the hydrogen will have

* From Mathias Duval.

penetrated into every portion of the pulmonary apparatus, as experience has shown. If the precaution is observed not to have a naked flame about, the use of hydrogen is perfectly safe. The contents of the bell-jar are then analyzed. By means of endiometric analysis the proportion of hydrogen contained in the bell-jar can readily be calculated; and since the bell-jar and the respiratory apparatus, at the moment when the advent of air terminates the experiment, form a closed system in which the hydrogen is uniformly diffused, the total capacity of the system can readily be obtained by a simple calculation; after which, by subtracting the capacity of the bell-jar, the capacity of the respiratory apparatus alone can be determined.

By a similar method it is possible to calculate the **coefficient of ventilation** (Gréhant), which possesses a peculiar importance in aërotherapy. In a word, it is the only method of studying the renewal of air in the lungs. This coefficient of ventilation is, according to Gréhant, the quantity of fresh air that remains in a unit of volume of the ventilated space after each respiratory movement; or, in other words, the coefficient of pulmonary ventilation is the relation between the quantity of fresh air remaining in the lungs or in the bronchial tree and the capacity of the respiratory apparatus as just defined. At each expiration a portion of the fresh air introduced during the inspiratory phase is expelled along with the vitiated air. The proportion of pure air remaining in the lungs is therefore easy to determine by making the subject breathe pure hydrogen instead of air during one inspiration. The gas expelled during the ordinary expiration that follows is then analyzed, and from this the quantity of hydrogen remaining in the lung can be calculated. By this method Gréhant found that in ordinary respiration two-thirds of the inspired air remains in the lungs, but that forced expiration diminishes this residual quantity by one-half.

It follows, therefore, that more air circulates in the lungs than is required to bring about the necessary interchange of gases between the air and the blood, and it is generally admitted that of the 100 or 105 cubic centimeters of oxygen (say 6 cubic inches) contained in an ordinary inspiration, only about one-fifth, that is, from 20 to 25 cubic centimeters (say 1.25 to 1.5 cubic inches), enters the blood. During the twenty-four hours the average quantity of air introduced into the lungs is from 10 to 12 cubic meters (say 350 to 425 cubic feet), while not more than 0.570 cubic meter (20.09 cubic feet) or 570 liters (150.6 U. S. gallons) of oxygen enter the blood, or, in round numbers, about 800 grams. It would therefore appear *à priori* superfluous to increase the pulmonary ventilation if this factor alone were to be considered.

As a matter of fact, however, other very important factors enter into, and materially modify the equation, as will be shown later. Of the 500 cubic centimeters (30.5 cubic inches) of air that make up an ordinary inspiration there remain in the lung, after an ordinary expiration, about 330 cubic centimeters (20 cubic inches). The average capacity of the respiratory apparatus can be estimated at about 3000 cubic centimeters (3 liters or quarts, say 183 cubic inches). The coefficient of ventilation is therefore 0.113, or, in other words, each unit of volume of the respiratory apparatus—that is to say, each alveolus—renews at each respiration a tenth part of the air that it is capable of holding; so that the entire quantity of air contained in an alveolus requires ten respirations for its renewal.

Effect of a Forced Expiration.—After a forced expiration the quantity of fresh air retained in the lungs is diminished; but the volume of the lungs also diminishes, hence there is little change in the respiratory coefficient. This forced expiration is, however, followed by a more vigorous inspiration because the reserve air must be renewed, and, if respiration now continues at an average rate, the renewal of the air will be accelerated.

Effect of a Forced Inspiration.—The quantity of air retained in the lungs is increased, and the coefficient of ventilation becomes greater. It is a remarkable fact that the increase in this coefficient is almost exactly proportionate to the augmentation of the quantity of air inspired, over and above the mean quantity of 500 cubic centimeters (30.5 cubic inches); but if the quantity of inspired air falls below the mean, the coefficient of ventilation diminishes more rapidly than does the quantity of inspired air. In other words, it appears from Gréhant's figures that while two inspirations of 500 cubic centimeters (30.5 cubic inches) each are approximately equal to a single inspiration of 1000 cubic centimeters (61 cubic inches), two inspirations of 300 cubic centimeters (18.3 cubic inches) each scarcely exceed in renewal value one inspiration of 500 cubic centimeters (30.5 cubic inches). This disproportionate increase and diminution of the coefficient of ventilation, with increase and diminution in the volume of tidal air, is shown in the table following:

RESPIRATORY VOLUMES AND COEFFICIENT OF VENTILATION

Volume of Inspired Air	Volume of Expired Air	Volume of Pure Air Expired	Volume of Pure Air Retained	Volume of Lung after Expiration	Coefficient of Ventilation
300 c.c.	345 c.c.	161.5 c.c.	138.5 c.c.	2295 c.c.	0.060
500 "	475 "	180.0 "	320.0 "	2365 "	0.135
600 "	625 "	231.2 "	368.2 "	2315 "	0.159
1000 "	1300 "	464.1 "	535.9 "	2004 "	0.262

The **diagnostic possibilities of spirometry** are evident. By accurate measurement the extent of pulmonary impairment and the phase of respiration affected can be determined; while the effect of treatment may be the subject of exact observation.

The **diagnostic possibilities of pneumatometry** have been reviewed since Waldenburg's time by Elsberg.* Emphysema and phthisis are the two diseases in obscure or incipient cases of which pneumatometry is most useful as a diagnostic aid; but the method has also been used not only in other diseases of the respiratory organs, but also in diseases of the circulatory system. In emphysema the normal relation between inspiratory and expiratory pressure is reversed; inspiratory or negative, becoming greater than expiratory pressure. The pneumatometer makes a diagnosis of emphysema possible in the incipient stage before any suggestive symptoms have developed and while yet all other methods of examination fail. In cases of asthma it is a valuable means of determining whether emphysema is present as a complication. Phthisis is characterized by a general reduction of the respiratory power, both inspiratory and expiratory pressure being diminished, but with maintenance of the normal relation. In valvular heart disease the respiratory power as a whole is reduced; but some differences have been determined according to the valve affected. In mitral disease, whether obstructive or regurgitant, expiration is said to be chiefly affected; while in aortic disease the greatest reduction is observed in the inspiratory pressure.

The pneumatometer furnishes a means of accurately describing dyspnea both qualitatively and quantitatively even before the patient himself has become aware of any respiratory disturbance; in addition, it reveals certain abnormal conditions that may be caused by various diseases between which differential diagnosis with the aid of other methods of examination must decide. Also it affords an index of the result of treatment.

METHODS OF AËROTHERAPY

Atmospheric air may be employed therapeutically in various ways. It acts upon the economy chiefly by penetrating into the air-passages and bringing about a gaseous interchange at the surface of the alveolar epithelium, but may also be utilized for direct or indirect topical effect both externally and by inhalation. The following **modes of application** may be resorted to.

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* "Pneumatometry," by L. Elsberg, "N. Y. Med. Jour.," 1875, vol. XXII, page 469.

(A) The **physical** and **chemical properties** of air under (1) **ordinary pressure,** or of air under (2) **modified pressure,** may be utilized (*a*) on the external surface of the body; (*b*) on the respiratory surface; or (*c*) on both respiratory and external surfaces simultaneously.

(B) Modifications may be induced in the **ventilation of the lungs** by calling into action systematically and voluntarily certain respiratory movements: (1) **general gymnastics**; (2) **respiratory gymnastics.**

Before considering methods involving modification of the air, physically or chemically, we shall describe briefly a special method of treatment that within the last decade has assumed great prominence in connection with pulmonary tuberculosis, and consists simply in constant exposure of the patient to open air.

The Open-air Treatment of Pulmonary Tuberculosis

The great importance of an **outdoor life** in the management of phthisical patients was recognized in very early times. It was **urged,** for example, by Sydenham, and after him even more earnestly by Beddoes in England, Rush in America, and others of the eighteenth and early nineteenth centuries, among whom may be cited the great philosopher Benjamin Franklin. The systematic employment of the **open-air treatment** as a special method, in the rigorous sense of the term, pertains, however, to our own time, and the credit of it must be awarded to Herrmann Brehmer. Since he first pointed the way a number of private, and, in recent years, public, sanatoriums for the treatment of consumptives have been established in Europe and America. For a description of the various localities where such sanatoriums are to be found the reader is referred to volume IV of this series. Trudeau in the Adirondacks and Solly in Colorado were the pioneers in this field in America. The former's establishment is the model after which other institutions of the kind have been planned, and while a suitable climate is a desirable and helpful factor, the excellent results achieved in almost every part of the country tend to show that a plentiful supply of pure air—regardless of the altitude or meteorologic conditions of the locality—is the only indispensable requirement.

The methods pursued at the various sanatoriums present little variation. Life in the open air, winter and summer, day and night, is the essential feature. It seems to be the general experience that the comforts of life and the theoretic dangers of exposure to inclement weather can safely be disregarded; Trudeau finds that tuberculous patients improve more rapidly during the colder than during the warmer months. Smyth, who relates his personal experience at Nordrach under the care of

Dr. Otto Walther,* says that he not infrequently had an inch of snow on his blankets. At some localities tents are the only shelter, but whether the patients are housed in cottages or in tents, the free access of air must be absolute and uninterrupted. Drafts are not feared. At night the windows, which should constitute at least one side of the room or ward, are kept open; in some places the sashes are removed altogether; the sides of the tents are rolled up, except in the severest storms. In very cold weather the head and hands may be protected

FIG. 7.—OPEN-AIR REST-TREATMENT AT HOME.—(*From Knopf.*)

with woolen cap and gloves, and at all times the patients are well provided with blankets. In summer the beds or reclining chairs are moved into the open or into covered porches during the day; for the winter most places are provided with glass porches or sun-parlors, where the patients spend their days in bed or reclining on steamer-chairs.

Some difference of opinion exists on the subject of **exercise,** pulmonary gymnastics being prescribed in some institutions even during

* "Practitioner" for July, 1901.

the active period of the disease; most authorities are agreed, however, that it is a safe rule to forbid any kind of exercise so long as the temperature exceeds 100° F. (37.7° C.). As the patients improve they are made to take exercise graduated according to their strength, and, in charitable institutions, to do light work.

Three important indications are met by the open-air treatment: reduction of the fever, improvement of the appetite, and the induction of sleep. Cough and night-sweats disappear in a short time, and, as a logical consequence, the medicinal treatment is reduced to a minimum. Antipyretic drugs are never used and expectorants are rarely required. Suralimentation is practised in many places, especially in the German resorts, where it is pushed to an almost incredible degree; even bed patients with considerable pyrexia are placed on a full diet of meat and vegetables. Trudeau and Flick * content themselves with giving their patients three full meals a day, allowing them to drink milk between meals if they have a desire for it; when, however, there is anorexia, the patient is given raw eggs beaten up with milk every two or three hours.

The open-air treatment, like all other therapeutic methods, is to be 'mixed with brains' in its application to individual cases. Utilized judiciously and not made into a fetish, it need not be confined to sanatoriums. Intelligent patients treated at their own homes can be persuaded to walk or ride abroad—if advisable, even in inclement weather—and when houses are favorably situated, as in the country or in suburbs, the porches and grounds can be utilized for rest in the open, with or without partial shelter (Fig. 7). Tents may be erected on private grounds,† care being taken to guard against dampness by elevating the floor upon thick beams and making it of two layers of close-fitting boards placed crosswise with a layer of felt between. If necessary, a trench about six feet deep and lined with sods should be made about the tent to insure drainage of the ground beneath the floor. Almost everywhere, it is at least possible to keep the windows open, if the physician be insistent.

* Through the efforts of Dr. Lawrence F. Flick, of Philadelphia, a free hospital for poor consumptives was established at White Haven, Pennsylvania, and has been conducted on the open-air plan during the past two years. The results of the first year's work are encouraging.

† Dr. A. M. Holmes, of Denver, Colorado, has recently described (N. Y. Med. Journal, Nov. 20, 1902) a '*Sanitary Tent Cottage*,' which obviates most of the disadvantages for long-continued habitation pertaining to the primitive tent in ordinary use. A portable wooden frame of special construction is ingeniously bolted together, and covered with canvas in such a way that more or less of the tent can be folded back or the whole surface shut in as desired. A space at the top between the frame and the canvas is always free for the passage of air (' eave ventilation') while excluding rain and snow. There are also windows to admit light, when the canvas covering is kept down.

CHAPTER II

THE USE OF AIR MODIFIED IN COMPOSITION AND TEMPERATURE

Composition—Purity, Bacteriology; Effects of Vitiated Air; Chemical Modifications of Air. Temperature—Liquid Air; Cold Air; Hot Air.

A. (1) THE PRESSURE OF THE AIR REMAINS THE SAME, BUT ITS PURITY, ITS COMPOSITION, AND ITS TEMPERATURE VARY

Composition of the Air

There is, as we have seen, comparatively little variation in the quantity of oxygen and nitrogen contained in different kinds of air—city air, country air, forest air, or sea air; even the quantity of carbon dioxid varies little under conditions of comparable pressure. But the same is not true of its richness in ozone and of the quantity of aqueous vapor it contains; above all, the percentage of mineral, vegetable, and animal dusts is subject to wide variations.

Purity of the Air—Bacteriology.—The investigations on the purity of the air, begun by Ehrenberg, Schwann, and Tyndall, and the more convincing researches of Pasteur on the difference in the number of germs contained in the air of glaciers and that of inhabited regions, have since been pursued with great patience by Miquel and by Freudenreich. We cannot dwell at length upon this subject of primary importance, which should be studied as the basis of climatotherapy; it is, however, impossible not to touch upon it here.

In 1830 Ehrenberg discovered in air the ova of infusoria and the spores of cryptogams. The fact was verified in 1832 by Gaultier du Claubry. In 1849, Swayne, Britton, and Budd believed that they had discovered in the air of rooms occupied by cholera patients the germs of this disease. The researches of Pouchet, in 1860, disclosed the presence of numerous molds. Since then, we may mention the works of Dancer, Angus Smith, Pasteur (1862), then those of Maddox, of Douglas Cunningham, of Schoenhauer, and especially of Miquel. The following is a list of the impurities found more or less constantly and in variable

proportions: **Mineral particles**—carbon, flint, earthy salts, calcium carbonate, calcium sulphate; **organic particles**—fibrous and cellular debris, epidermic scales, fragments of trachea, vegetable fiber, cotton fiber, linen fiber, hemp fiber, grains of pollen. Particles of starch are more common in the city.

The **number of living germs,** small in winter, increases rapidly in pring, remains high in summer, and declines rapidly in the autumn.

1878, autumn, ...	11.3 in the liter (quart).
1879, winter, ...	5.5 in the liter (quart).
" spring, ...	15.7 in the liter (quart).
" summer, ...	28.9 in the liter (quart).

The mean is 15.4 in the liter, which gives 15,400 bacteria to the cubic meter (approximately 481 in the cubic foot). The variations in the figures are considerable—from 2000 to 120,000. A rainfall of some duration always induces a recrudescence of microbes, and this recrudescence occurs often at the same time as the shower, the germs contained in the upper strata of the air being precipitated by the rain.

M. Miquel, who first determined the number of living bacteria, found figures varying from 23 to 197 according to season. These variations are measurably analogous to those given at the present day. The exact relation between meteorologic conditions and the incidence of bacteria in the air is still in doubt. The number of bacteria, always greater during the rainy season, increases during the period when the earth is dry, then declines when the dryness is prolonged beyond ten or fifteen days. This, however, is a rule that is quite empiric.

We have already pointed out the influence of the **wind.** Aërial currents, as the vehicle of all the dust collected upon the surface of the earth, contain living germs. It is sufficient to open a Pasteur tube, in order to see the infusion at the end of several hours' exposure in the incubator become turoid and filled with micro-organisms. The germs of the air are, as Pasteur has demonstrated, most variable, and most irregularly distributed. They are more rare in caves, where the air is little agitated, than in an open place; much more rare at an elevation than at sea-level, where exist conditions of humidity favorable to their development. They are very rare at heights (Mer de glace) (Pasteur and Balard). The actual number of bacteria at the center of Paris is at least ten times greater than at Montsouris, one of the fortifications, but the variation pursues almost exactly the same proportional course. The number of living bacteria is much greater in hospital wards than outside. According to the estimate of Duclaux, there are at least 100,000 spores of

bacteria in a cubic meter of air in the wards of hospitals. The number of bacteria in the streets about the hospital increases during the summer, because of the freer ventilation of the rooms. This explains why at certain periods a hospital may become a focus for the spread of contagious diseases in its neighborhood.

Among the atmospheric bacteria, a small number have been identified. In countries where the silk industry is followed, Pasteur found the causative microbe of silkworm disease (pebrine) in the air. He has also found in the air a urea-splitting ferment, and Miquel has isolated several micro-organisms capable of rendering urine ammoniacal. In the wards of hospitals there have been found various pathogenic microbes, such as those of suppuration and those of tuberculosis (Cornet). It is, therefore, necessary in applying the various methods of aërotherapy, to take precautions to insure a reasonable degree of purity of the air.

From the foregoing facts we see that it is necessary to abandon the opinion which had been established in science, as to the invariability of the air; an invariability inferred from the observation that the air had everywhere the same composition. With Hippocrates, contemporary research has demonstrated that there is not one air, but numerous kinds of air.

Apparatus for Counting Bacteria in the Air.—We shall not here describe the procedures for counting the germs in the air. We wish to refer only to the two forms of apparatus most commonly employed. That of Miquel consists of a bulb provided with two tubes through which a certain quantity of air is passed. The apparatus of Hesse consists of a glass tube the inner wall of which has been coated with a thin layer of nutrient gelatin and through which a given quantity of air is passed. The procedures of Frankland and of Petri are governed by the same principle. A mass of hair is employed to filter the air, and with the hair is incorporated gelatinized cotton. In the apparatus of Strauss and Wurtz a definite volume of air is passed through nutrient gelatin. Figure 8 is a diagram of the apparatus employed by Christiani which combines the advantages of the apparatus or aëroscope of Miquel and that of Strauss and Wurtz; it contains a layer of solidified gelatin upon which is superposed one of bouillon.

Effects of Vitiated Air

The consideration of the evil effects of confined air pertains rather to the domain of hygiene than to that of therapeutics, but may here be taken up briefly.

When human beings are confined in a restricted medium, the increase in temperature and the proportion of watery vapor in the air is of secondary importance as compared with the augmented volume of **carbon dioxid,** and without doubt, also, the presence of chemical products, as yet undetermined, exhaled by the lungs. Gréhant has demonstrated that when carbon dioxid is present in a proportion exceeding from 1 part in 17 to 1 part in 9 of the surrounding air, the pulmonary exhalation of that gas becomes reduced and eventually ceases. Should its tension in the atmosphere exceed that in the blood, carbon dioxid may even be absorbed. In closed spaces filled with oxygen animals will die by reabsorption of the carbon dioxid excreted, even though the air may still contain 50 per cent. of oxygen (Worm Mueller). When the proportion of carbon dioxid in the atmosphere is from 6 to 8 per cent., there is neither absorption nor exhalation of this gas through the lungs, but even when the air contains only 1 per cent. of carbon dioxid, pulmonary exhalation is unfavorably modified. Hygienists fix 7 parts in 10,000 as the highest proportion permissible.

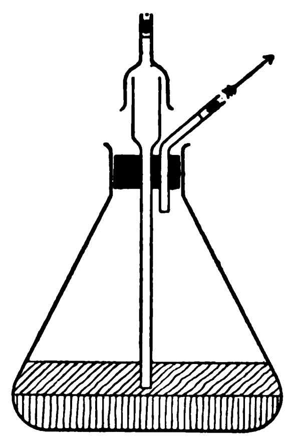
FIG. 8.—CHRISTIANI'S APPARATUS.

The **organic matters** eliminated by the lungs are represented by volatile bodies, such as those which give the characteristic odor to the breath of one who has eaten garlic or onions, or to that of a drunkard. Chloroform, sulphuric acid (experiments of Claude Bernard), creosote, terebinthinates, and other drugs are eliminated in part by the lungs. Under normal conditions it is almost certain, moreover, that the expired air contains certain volatile principles having little or no odor, but which may be possessed of a marked toxic action.

These brief statements will suffice to demonstrate the noxious effects of confined air, and the necessity, from the hygienic point of view, of respiration in the open air or, at least, in air that is frequently renewed. Nevertheless it is not necessary to believe that the danger from confined air is due to the presence of germs exhaled by persons affected with bacterial pulmonary lesions. Lister had already foreseen the purity of the air in the lungs. Tyndall demonstrated it by resorting to a procedure devised by him for the purpose of establishing that gases deprived of solid particles are incapable of giving off light. He finds, thus, that the last portions of air expired are optically pure. Gunning conducted

the expired air through a flask provided with two tubes and filled with bouillon, and found it sterile. More extensive and more precise observations led Strauss to the conclusion that the expired air is almost completely free from germs. Virulent germs have indeed been found in the rooms of sick persons; but they are not derived from the breath. The infected sputum is deposited upon the floor or upon the bed-linen, where it dries, and as it is disseminated through the atmosphere in the form of dust, liberates the bacteria.

Chemical Modification of the Respired Air

The systematic chemical modification of respired atmospheres for therapeutic purposes dates from the latter part of the eighteenth century, and is especially associated with the names of Priestley, Percival, Beddoes,* Davy and Watt. The proportion of oxygen or other normal constituent of the atmosphere may be increased or decreased at will or any gas or vapor may be added in such quantity as desired. The artificial air may be inhaled from a suitable reservoir, or it may fill a cabinet or apartment in which the patient remains at rest or moves about for any predetermined period. The subject, however, may best be considered in connection with the general topic of medicinal inhalations, and will accordingly be taken up in Part II of this volume.

Liquid Air

Air, in the state in which we know it, is a gaseous medium; but within recent years it has been successfully liquefied. The application in medicine and in surgery of liquid air is too recent to permit us to enter here into great details, the more so as the question is most often not the utilization of the air itself, but of the intense cold that is developed by its evaporation. It should be recalled, however, that a proposition has been made to liquefy mountain air, sea air, etc., in order to reproduce such atmospheres at any point. Campbell White has utilized the refrigerant action of liquid air in the treatment of **carcinoma** and of certain **nervous affections,** such as herpes zoster, sciatica, costal and intercostal neuralgia. He uses a small brush dipped in the solution, which he applies to the diseased tissues or to the skin. The latter becomes perfectly white and bloodless, but the circulation is restored promptly if the application has not been too prolonged. The result is the production of **complete anesthesia.**

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*See especially Beddoes and Watt, "On Factitious Airs," London and Bristol, 1794 to 1796.

Temperature Modifications of Air

The **temperature** of inspired air may be reduced systematically, but the experiments of physiologists have demonstrated that in all cases in which the thermic reduction does not exceed certain limits, the air, before reaching the lungs, is warmed to such a degree that it reaches the alveoli at ordinary temperature.

Drake employed **cold air** at 32° to 33° F. (0° to 0.6° C.) in the treatment of **chronic catarrhal conditions of the lungs,** and observed the cough diminish, the pulse become fuller and slower, and the general state improve (Ramadge, Coxe). Langenbeck proposed the placing of a bit of ice in the reservoir of his respirator in cases of **fever, tuberculosis,** and **hemoptysis.** From recent observations by Pasquale di Tullio on the effects of cold air in hemoptysis, it would appear that favorable and rapid results may be obtained by means of this agent when ordinary medicinal treatment with such remedies as tannic acid, lead acetate, opium, or acid drinks fails to bring relief. Tullio recommends an apparatus constructed by A. Tursini, the principle of which is the same as that of the cooling device used in distilling apparatus. The air, before reaching the mouth, traverses a convoluted tube ('worm') immersed in ice, or in a refrigerant mixture.

Recently the employment of **cold-air baths** has been proposed for therapeutic purposes; and, according to R. Pictet, **psychrotherapy** is useful in certain conditions. Wrapped in thick coverings, the patients descend into vaults where an excessively low temperature, —120° C. (—184° F.), prevails. Under these circumstances there occurs on the part of the organism an unusually intense reaction to such extreme cold, whence results marked stimulation of the functional activity in all vital organs. (See volume IX.)

Hot air has been more often employed. We shall mention only the attempts to treat **bronchopulmonary affections** by **superheated dry air.** For this purpose excessive temperatures have been proposed—so high as 180° C. (356° F.). Dry air may be breathed **through the nose** at an exceedingly high temperature. At the end of an hour and a half of respiration through the nose of air at a temperature of from 50° C. (122° F.) to 350° C. (662° F.) the body-temperature, however, is elevated scarcely one degree, and, besides, a large part of this thermic elevation must be attributed to modifications in the respiratory rhythm (Sehrwaldt). The introduction of hot air **directly into the trachea** has been proposed, but the tracheal mucous membrane is much more sensitive than that of the nose or mouth, and it has not been possible to exceed temperatures of 80° C. (176° F.). Under such circumstances,

respiration is rapidly accelerated, but the temperature of the lungs is elevated scarcely a degree.

Weigert was the first to propose the systematic treatment of **pulmonary** and **laryngeal tuberculosis** with inhalations of hot air. For this purpose he had constructed an apparatus for heating dry air to exceedingly high temperatures. The first published results of this new method of treatment appeared to be so favorable that certain observers believed themselves justified in affirming that under the influence of the high temperature there resulted destruction, or at least attenuation, of the tubercle bacilli. Later researches, however, have shown how ill founded was this opinion. It will suffice to state that the precise and absolutely conclusive researches of Mosso and Rondelli have proved that superheated dry air becomes cooled in the upper air-passages, by inducing abundant evaporation, so that when it reaches the ultimate bronchial ramifications its temperature scarcely exceeds 37° C. (98.6° F.). Cervello had arrived at slightly different conclusions. When the thermometer in the apparatus of Weigert registered 250° C. (482° F.), the inspired air had a temperature of 60° C. (140° F.) when it entered the trachea, and 45° C. (113° F.) when expired. In using the apparatus of Weigert, A. de Vestea endeavored from the outset to assure himself experimentally of the temperature of the air on reaching the lungs. Although the conditions of the experiment were not beyond criticism, the expiratory apparatus being represented by a tube, his conclusion is that air brought to a temperature of 200° C. (392° F.) reaches the trachea at a temperature of 48° C. (118.4° F.) at most, and the alveoli at a still lower temperature. Vestea, wishing to measure this temperature directly, employed a hypodermic syringe, the needle of which he introduced into the lung. The lumen of the needle contained substances which remain solid at the normal temperature of the body, and melt at a temperature a little above the normal. Such substances are phenol, menthol, thymol, naphthylamin, diphenylamin, paraffin. He verified the accuracy of this procedure in guinea-pigs rendered febrile by inoculation with the virus of rabies. In a tuberculous patient who had breathed hot air (from 200° to 220° C.—392° F. to 428° F.) for a quarter of an hour, with the apparatus of Weigert, Vestea applied his method and was able to determine that the temperature in the parenchyma of the lung did not exceed 40° C. (104° F.), a temperature insufficient to modify the vitality of the tubercle bacillus. Nycamp arrived at identical conclusions. Halter thought that the tubercle bacillus can be destroyed by frequent exposure for a short time to a temperature of 41° C. (105.8° F.). Recent researches have shown that this statement

is incorrect. In order to destroy the virulence of tubercle bacilli in the sputum, it is necessary to employ a temperature of at least 80° C. (176° F.) (Dujardin-Beaumetz and Dubief). Trudeau, who has made observations upon the employment of heated air in cases of pulmonary tuberculosis, has not observed any modification in the evolution of the disease, nor any influence upon the virulence of the bacilli. Shurly, with the apparatus of Weigert, is said to have observed that the patients feel better, and that their dyspnea is diminished; but, as a matter of fact, the final result is negative.

After the method had failed in the treatment of bronchopulmonary affections, experiments were made in the treatment of tuberculosis of the **larynx** and the **trachea,** as much more readily accessible to the action of superheated air. Möser proceeded as follows: his patients breathed superheated air in his presence for from four to ten weeks, from an hour to an hour and a half daily, sometimes for a longer time, with the apparatus of Weigert. Some patients continued the treatment at home for three months. In accordance with the susceptibility of the subjects, the temperatures employed varied between 160° C. (320° F.) and 240° C. (464° F.). The first sittings were usually attended by a series of unpleasant sensations and attacks of cough without noteworthy consequences. Möser noted burns of the uvula and of the pillars of the fauces, which in general healed rapidly. There followed often, especially at first, slight edema of the posterior wall of the larynx and of the vocal cords, causing alteration in the voice. The frequency of the pulse was slightly increased at the beginning of each inhalation sitting, and the amplitude of the respiratory movements was greater. The body-temperature was not affected. Upon the state of the lungs the action of hot air was negative, or in certain cases detrimental. On the other hand, in a case of **bronchiectasis** with fetid expectoration, Möser obtained speedy and permanent relief. Tuberculous or syphilitic **ulceration** of the larynx was rapidly modified in a favorable manner, even when quite extensive, and after the usual measures had failed. Clado also has seen tuberculous laryngitis improve under this influence.

To sum up, the treatment of pulmonary tuberculosis by inhalation of hot air is rather injurious than useful, and it is especially as a local agent that hot air has been employed with success (Dujardin-Beaumetz, Constantin Paul, Trudeau).

Effect of Hot Air on the Skin.—Healthy skin and diseased skin do not react in the same manner. When a current of hot air is directed upon the **healthy skin,** the latter becomes pale and contracts in consequence of vasoconstriction, causing ischemia in the affected region. In the case

diseased skin it will be observed that the area affected by lupus becomes surrounded by newly formed vessels and forms a distinct prominence above the level of the healthy tissues. In the course of several days the healthy skin resumes its normal aspect, while the diseased areas begin to undergo necrosis.

Apparatus for the Local Use of Hot Air

Hollānder has, since 1897, applied hot air to the treatment of **lupus.** According to his opinion, hot air acts by reason of its antiseptic and hemostatic power. He employs either absolute or relative cauterization. He says: "The instrument by means of which I bring about this progressive necrosis is simple, convenient of application, and quite capable of fulfilling the purpose for which it is intended. It consists essentially of a long metallic rod terminating in a point and pierced by a central opening, through which a current of air may be passed by means of a rubber bulb. In using the apparatus, it is necessary (1) to expose the metallic rod to the action of a flame sufficiently hot to produce the desired temperature; (2) to project a current of air by means of the rubber bulb. By utilizing a source of heat sufficiently intense, the current of air, which, after having traversed the opening in the incandescent metallic rod, escapes through the free opening, may attain a temperature of more than 300° C. (572° F.)."

For a long time **dentists** have employed hot air by means of an exceedingly simple apparatus. This consists essentially of a bulb and a metallic tube provided with a wooden handle to which the bulb is adjusted. The tube is continued in a convoluted form into a closed metallic sheath, and ends in a point. It is contained in a hard-rubber case, from which only the pointed extremity projects. The tube is heated for several minutes over an alcohol lamp at the point where the convoluted portion is contained in the sheath, and is then placed in its sheath. The bulb is then compressed, and the air is heated in passing through the convoluted tube.

F. Jayle has employed aërothermotherapy at the Hôpital Broca in a certain number of cases of simple and specific **ulceration** situated in different portions of the body. He experienced complete failure in some cases, amelioration in others, and favorable results in still others. He describes his apparatus as follows: I had constructed by M. Collin, at the end of last year, an apparatus that appears to me to present many advantages. The temperature obtained may exceed 200° C. (392° F.) quite readily, and is easily regulable. The apparatus is managed without difficulty, the source of heat is portable and requires little care.

It consists of an ordinary thermocautery, with two modifications: (1) About the blade of the cautery there is placed a sheath covered externally by a layer of flax, in order both to prevent radiation and to protect the operator and patient from contact with a heated surface; (2) the tube of the bellows, before reaching a flask containing essence of turpentine, subdivides into two tubes, one of which passes to this flask, while the other ends at the sheath that surrounds the thermocautery. From the foregoing the mode of action can be readily understood: The air from the bulb divides into two currents; one portion supplies the thermocautery and maintains it at red heat, the other enters the sheath and is heated in passing over the cautery. Each compression of the bulb acts at once upon the thermocautery and upon the current of air. By this means a current of hot air is provided at the extremity of the thermocautery, which is thus converted into a sort of aërothermogen. In order to regulate the temperature and to obtain by means of the same apparatus widely different temperatures, it will suffice to recall that hot air is cooled in passing through a narrow opening. Consequently, by providing the sheath with a conical attachment having an orifice varying from 0.5 mm. to 1 cm. in diameter, different temperatures can be obtained, which are almost constant for each opening. The current of hot, dry air carries with it the products of combustion of the thermocautery, so that if one wishes to have pure air he may substitute for the concentric sheath a tube placed in juxtaposition with the thermocautery. This becomes heated by contiguity, and the air that passes through it becomes heated in its course. The degree of heat is less than is obtained with the hot-air bulb used in dentistry. The apparatus is operated as follows: The thermocautery is removed from its sheath. At the base of the latter is a stopcock that is closed after all the air from the bellows has reached the thermocautery. The latter is brought to a red heat as under ordinary circumstances; then it is placed in its sheath, which is rapidly warmed. The stopcock is opened, and the air from the bellows divides into two currents. One of these continues to pass through the thermocautery and the other enters the sheath and constitutes the current of hot air.

Balzer successfully employed the method of Holländer in the treatment of **chancroid.** Before him, Bourgeois had applied hot air in the treatment of **infectious ulcers of the cornea.** Gautier and Larat, and after them Löwenberg, have treated **ozena** with hot air.

The following is a description of the apparatus employed by **Gautier and Larat,** as given in the thesis of one of their pupils, Dagail: Compressed air obtained from *La compagnie Popp* is distributed at will in an

apartment when one is in proximity to a *sector*. By means of a stop-cock, the air is withdrawn with such rapidity and in such quantity as may be desired. This air, in the case in question, reaches a flask with a double tube containing water charged with medicinal substances; from this it escapes, through one of the tubes, in order to circulate in a short convoluted tube. At the free extremity of the latter a flexible metallic tube is adjusted, and the free extremity of which, finally, is provided with another short rubber tube and a glass nasal cannula of special form. The source of heat may be electricity, gas, or alcohol. A lamp placed beneath the convoluted tube is sufficient for heating purposes. When the air-cock is opened, the air is purified by bubbling through the water, in which it becomes charged with appropriate medicinal vapors, passes through the convoluted tube, in which it is progressively heated, and finally passes through the nasal fossæ, the pharynx, and the mouth. The supply of air may be increased at will, and the degree of heat may be regulated by the intensity of the thermal source. Compressed air from any source may be utilized similarly.

E. Larue Vansant (1897) employs insufflations of hot air in the treatment of **otorrhea, otalgia, Eustachian catarrh,** and certain other affections of the **nose,** the **pharynx,** and the **larynx.** For the relief of the **pain** (headache) that is so frequently observed when the openings of the sinuses in the nasal cavity become obstructed, the insufflation of hot air is often quickly effective. Vansant uses an instrument in the form of a revolver, which the physician holds in his hand by the curved end. At the point of union of the handle and the straight portion there is a bulbous enlargement, which may be heated by means of an alcohol lamp. The air is conveyed to this point by means of a bulb or a compressed air reservoir. It is heated at this point, and, with the aid of a capillary tube adapted to the anterior portion of the instrument, is directed to the diseased spot. Vansant must be given credit for the systematic use of superheated air in the treatment of affections of the upper air-passages and of the ear. The writers who have followed him have either modified his instrument or have defined more exactly the indications for the method. Thus Amberg, in 1898, successfully employed aërothermotherapy in the treatment of **ozena** and various other **nasal affections.** Hessler, in 1900, following Andrews, employed hot air without much success in the treatment of chronic suppuration of the ear. Lately Lermoyez has repeated these attempts, and concludes that aërothermotherapy yields the best results in cases of **spasmodic rhinitis, congestive rhinitis, hypertrophic rhinitis, hydrorrhea** with nasal obstruction, **rhinorrhea, sneezing, asthma, nasopharyngeal catarrh, otalgia, tubal**

and tubotympanic catarrh with deafness, vertigo, nausea, or ringing in the ears. The cure is permanent, and the condition is not one merely of transitory amelioration. **Acute coryza** and **hay-fever** may also be advantageously treated by this method.

Lichtwitz employs an apparatus consisting of a convoluted metallic tube heated by a Bunsen burner, the air being furnished by a pump operated by electricity. He has by this means obtained good results, especially in cases of **spasmodic** and **subacute rhinitis.**

Aërothermotherapy, so called, undoubtedly yields good results in the treatment of certain affections of the nose; but I do not believe that this is really to be credited to aërotherapy. I should prefer to use the term 'thermotherapy,' because the quality of the air is of little importance; it is the temperature alone that is effective.

Similar comment may be made concerning the application of superheated dry air to the **extremities** or other portions of the **body,** inclosed in special 'cabinets,' 'cylinders,' 'thermophors,' and the like. Tallermann and others use very high temperatures—400° F. (205° C.)—in these apparatus; principally for the treatment of affections of the **joints,** but also to induce perspiration and to influence metabolism in certain **diathetic** disorders, such as gout, rheumatism and the like.

W. T. Hedley has not exceeded temperatures of from 60° C. (140° F.) to 100° C. (212° F.). He has employed hot air in the treatment of subacute articular rheumatism with rapid relief of pain, and in cases of chronic articular rheumatism. (See under "Thermotherapy," vol. IX.)

CHAPTER III

PHYSIOLOGIC AND PATHOLOGIC EFFECTS OF THE COMPRESSED-AIR BATH

Pressure Modification—Barometric Pressure. Classification of Methods. Absolute Pressure Method. Differential Pressure Method. The Compressed-air Bath. Henshaw's Pneumatic Chamber or Domicilium. Historical Review. Diving-bells. Sturmius's Bell. Caissons. Physiologic Effects of High Pressure. Accidents Occurring During Decompression. Physiologic Effects of Moderate Excess Pressure. Effects Observed in the Pneumatic Chamber. Mode of Action of Compressed Air. Effect on the Lungs. Effect on the Circulation.

A. (2) AIR MODIFIED IN PRESSURE (AND IF NECESSARY IN COMPOSITION) IS APPLIED (*a*) TO THE RESPIRATORY SURFACE OF THE BODY; (*b*) TO THE EXTERNAL SURFACE; OR (*c*) SIMULTANEOUSLY TO THE EXTERNAL AND RESPIRATORY SURFACES

Barometric Pressure

Modifications in the **density** of the atmosphere may be utilized therapeutically by taking advantage of the **natural** variations of **barometric pressure** due to elevation, or by employing apparatus to effect predetermined changes of pressure—**artificial pneumotherapy.**

There is no evidence of any exact knowledge of atmospheric pressure before the middle of the seventeenth century. While Galileo had the first inkling of it, it was his pupil Toricelli who, in 1643, demonstrated its existence and invented the mercurial barometer—the same instrument that is in use to-day.

By **normal barometric pressure** is meant that mean pressure of the atmosphere which is found at the level of the sea. It is equal to the pressure (at 0° C.) of a column of mercury having a height of 760 millimeters (30 inches)—which is equivalent to a pressure of 1033 grams exerted on each square centimeter of surface, or about 15 pounds to the square inch. However, it must be noted that this mean pressure is not constant at the level of the sea. Least in the equatorial region—758 millime-

ters—it attains its maximum of 764 millimeters between the thirtieth and fortieth degrees of latitude, and decreases again toward the poles.

Change in mean pressure can be attained by a change in altitude. We cannot, however, accept without qualification Pascal's dictum that there is a constant relation between altitude and barometric pressure; for the static equilibrium of the atmosphere is far from perfect. Nevertheless the barometer is daily employed in scientific observations as a means of calculating elevation, at least approximately. In addition to the changes dependent on altitude, there are also **fluctuations in** barometric pressure due to heat, winds, rain, and other meteorologic conditions. These rarely exceed one inch of mercury, and in our studies of pneumotherapy may be disregarded—as they are too small for absolute effect, and, acting equally on both the respiratory and the external surface of the body, are devoid of differential effect.

Increase of Barometric Pressure.—There is no place on the earth's surface where the atmospheric pressure is markedly greater than the normal barometric standard. It is greatest in the region of the Dead Sea, 1300 feet below sea-level, but even here the increase is relatively slight and without definite effect on the organism.

Diminution of Barometric Pressure.—With increasing altitudes the weight and density of the atmosphere lessen. Air **naturally rarefied** therefore exists at stations elevated above sea-level; the pressure diminishing about one inch of mercury (½ pound to the square inch) for every 900 feet of elevation (approximately 1.82 cm. Hg for every 500 meters). From 1800 to 3000 feet (say, 600 to 1000 meters) is termed moderate altitude; 4000 to 5000 feet (say, 1200 to 1500 meters), high altitude; more than 5000 feet (say, 1500 meters), great altitude. From a physiologic and therapeutic viewpoint two distinct conditions must be borne in mind. In the first there is a **rapid change** from the normal pressure of low levels to the low pressure of the mountains, as in **ballooning** or **mountain-climbing,** and the organism experiences the phenomena described under the name of mountain-sickness—which will be discussed when studying the effects of **rarefied air.** In the second condition, **residence at high levels** is protracted or permanent and the organism after a certain transition period, usually of comparatively brief duration, becomes accustomed to its new environment. The mechanism and the effects of this adaptation (**natural pneumotherapy**) have been considered under the head of Climatology (vol. III, pages 57 to 63), and, in so far as necessary to a complete presentation of our subject, will also be taken up later in the present volume.

ARTIFICIAL PNEUMOTHERAPY

Beginning with the work of Tabarié in 1838, apparatus of various kinds have been utilized to modify atmospheric density at will for therapeutic purposes. The earliest classification of pneumotherapeutic methods, which was based solely on the movability of the apparatus employed,—*i. e.*, whether stationary or portable,—was soon abandoned in favor of a more rational division into **complete pressure** and **partial pressure** methods.* Oertel appears to have been the first to make this distinction. S. Solis Cohen employs the terms **absolute** and **differential,** and divides the latter group of methods into two subclasses: viz., **respiratory,** and **external** differential methods. The respiratory differential methods are again subdivided into **partial** or **monophasal,** and **complete** or **diphasal,** according as one or both phases of respiration are differentiated in pressure from the surrounding atmosphere. In the **absolute pressure** or Tabarié method the modification of pressure affects both the respired air and the surrounding atmosphere, the patient entering a pneumatic chamber in which the air is condensed or rarefied. In the **differential pressure** or Hauke-Waldenburg method, either the patient is made to respire air of modified pressure, while the density of the surrounding atmosphere remains unchanged (**respiratory procedures**); or the patient breathes air under normal pressure, while air of modified density is made to act, by means of various apparatus, on a portion of the body or on the entire body (**external procedures**).

In any of these methods, apparatus may be stationary or portable, being employed either to increase or to diminish the density of the air. They consist of **pneumatic chambers** in which the air is (highly) condensed or rarefied, so that the entire body is immersed in a veritable air-bath—**absolute pressure method**; of **gasometers** or other apparatus for (moderately) condensing or rarefying the air which the patient breathes through a tube and mouthpiece or mask, while the pressure of the surrounding air remains normal—**differential pressure method** †; and of

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* Lazarus ("Pneumotherapie," in "Lehrbuch der allgemeinen Therapie und der therapeutischen Methodik," Eulenburg and Samuel) divides pneumotherapeutic methods into **active** and **passive.** The active pneumotherapeutic methods are those in which the patient **voluntarily** modifies the respiratory conditions, with or without the aid of apparatus. In the **passive** methods the patient, without any volition on his part, is subjected to the action of **air** of modified density (chiefly of condensed air) either in pneumatic chambers—when the **entire body is acted upon**—or by means of apparatus acting only on individual portions of **the body.**

† **In certain forms** of differential-pressure apparatus, external atmospheric pressure on the **thorax or on the whole body** is modified while the patient respires through a tube the exterior

cabinets, cups, and similar apparatus for applying the action of air at modified pressure to individual portions of the body—**external differential methods.**

S. SOLIS COHEN'S SCHEME OF CLASSIFICATION

I. Absolute Pressure Methods
- positive (condensed-air bath)
- negative (rarefied-air bath)

II. Differential Pressure Methods

- **(a) Respiratory**
  - **complete or diphasal**
    - positive (condensed-air—inhalation and exhalation)
    - negative (rarefied-air—inhalation and exhalation)
    - alternating ([*a*] inhalation of condensed air, and exhalation into rarefied air; [*b*] inhalation of rarefied air and exhalation into condensed air)
  - **partial or monophasal**
    - positive
      - inspiratory
      - expiratory
    - negative
      - inspiratory
      - expiratory
    - alternating
      - inspiratory
      - expiratory
- **(b) External**
  - **general**
    - positive
    - negative
    - alternating
  - **partial or local**
    - positive
    - negative
    - alternating

THE COMPRESSED-AIR BATH

Historical Review

The idea of having patients breathe in a medium of condensed or of rarefied air quickly followed the discovery of atmospheric pressure. Bacon, in his "New Atlantis," had suggested the therapeutic use of chambers of modified atmospheres, and Henshaw, in 1664, was the first to attempt it, with the object of thus attaining at will and without change of residence the effects of a change of climate and altitude.

Henshaw's Pneumatic Chamber or 'Domicilium.'—The chamber was built of masonry and supplied with doors and windows that could be closed hermetically. It communicated with two bellows provided with valves which worked in opposite directions, in such a way that it was possible, at will, to obtain either compression or rarefaction of the air Henshaw also hoped to make use of this chamber as a means of combating the ill effects of sudden change of altitude, by placing the patient

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unaltered atmosphere, which is thus *relatively condensed or rarefied*. As the excess or negative pressure made use of is well within the limits of ordinary barometric fluctuations, the difference in method—involving no new principle—may be disregarded in this discussion.

under the barometric conditions of his accustomed surroundings. As to **physiologic effects,** he noted that the functions of the skin were increased, and respiration facilitated. **Therapeutically,** he observed a beneficent prophylactic and curative action in diseases of the lungs—for which he employed condensed air in chronic cases, and rarefied air in acute cases.

Diving-bells.—It was the study of the effects observed in diving-bells that gave the first positive data concerning the action of compressed-air baths. The invention of this bell, which, according to certain passages in the writings of Aristotle, must have been known to the ancients,* is commonly attributed to Sturmius, who lived in the beginning of the eleventh century. It was used for reclaiming from the bottom of the sea the piasters from the galleons wrecked at Capsdaque. Leonardo da Vinci, who was a student of nature as well as an artist, described and pictured a diving apparatus. According to Houssay, one of his manuscripts (MSS. 2037, folio 18, recto), originally in the Ambrosian Library at Milan and now in the library of the *Institut* at Paris, contains the drawing of a curious apparatus composed of two goatskins placed one above the other. The lower one incloses the chest, while the upper, as large as the lower, contains air and communicates with the atmosphere by means of a long tube the end of which floats on the surface of the water by means of a cork plate. To the left of the drawing, written backward, is the following in Italian: "*Questo strumento susa nel mare d'India, alchavere le perle affasi di corame conispessi cerchi accio che il mare nonlarichioga esta disopra il chompagno cholla barcha aspetta lo, ecquesto pesca perle e choralla cochialli di venti dancve (c?) et choraza di spuntoni preposti.*" ("This apparatus is used in the Indian Sea for securing pearls; it is made of leather with heavy hoops so that it may not collapse. Up above the [diver's] companion waits for him in a boat. The other gathers the pearls and the coral; he is provided with dark glasses and a cuirass bristling with many points.") In a collection of drawings by Leonardo da Vinci, coming from the same source and now preserved in the archives of the Louvre under the title of "*Disegni di Leonardo da Vinci*" (Carlo Giuseppe Gerli, Milanese 1784), there is one—Plate XXVII—which represents two heads under water. Opposite the first is "*Dandar sotto aqua*" ("for going under water"). Leading into the mouth is a long tube held up by a disk of cork. Under the tube is written "*channa*" ("tube"), and under the disk "*sughero*" ("cork"). The other head, situated below the swimmer, who is held up by a buoy, is covered by

* Alexander the Great was probably familiar with diving apparatus, and Polybius relates that Hannibal invented an apparatus for going under water.

a large mask which the diver puts on when he abandons his buoy and goes under water. The little opening at the extremity of the mask is the orifice of communication with the air, by means of the tube.

Taisnier, in a little book printed in Cologne in 1562, relates that in 1538 two Greeks went under water in the Tagus before the eyes of Charles V and his court. Covered by a large inverted cauldron they could go to the bottom of the river and reappear without becoming wet and without losing the flame from a candle they carried with them.

Sturmius's bell had no means of aëration and, according to Pauthot, the inventor advised divers to carry with them air in bottles which were to be broken in the bell. In 1665, to reclaim from the sea three cannons lost from the Invincible Armada near the Isle of Mull, Scotland, seventy-seven years before, large metal vats, which had been suggested by Francis Bacon in 1620, were successfully employed. Sturmius's bell was perfected in 1716 by Halley, who added a valve for the escape of the vitiated air; fresh air was supplied from cylinders which the divers opened at will. Spalding's improvements on Halley's bell were purely mechanical; he died while still working on it in 1788.

The Academy of Sciences of Haarlem for the first time took up the subject of compressed air from the physiologic and medical standpoint when, in 1782, it offered a prize for the solution of the two following questions:

I. What apparatus is best suited for carrying on experiments with condensed air in the easiest and safest way?

II. To determine, with such an apparatus, the action of condensed air in various cases.

These were to include, among other things, the effects upon animal life, upon the growth of plants, and upon combustion of different kinds of air.

Although this competition in Haarlem produced no definite result, it must be admitted that the Dutch scientists had a better appreciation of the possibilities of condensed air than the Academy of Sciences of Paris, which, when called upon to pass judgment on experiments performed with an apparatus constructed on the principle of a diver's outfit, saw in it nothing but a means of poaching.

We cannot dwell further upon the history of these first researches, and shall content ourselves with the mere mention of such names as Martin Friewald (1732), Leupold (1774), the Abbé de La Chappelle (1779), and especially Smeaton (1788), who conceived the idea of renewing the air in diving-bells by means of a force-pump.

On December 16, 1800, Achard wrote from Berlin to citizen van Mons a letter which was printed in the "Annales de Chimie" (vol. XXXVII, year

of the Republic IX [1800]), the following extract from which is worth quoting: "I have conducted some experiments upon the germination of seeds in condensed air, the result of which is that seeds germinate more quickly as the fluid is more compressed. The differences are quite marked. I have also experimented upon the longevity of animals exposed to various degrees of compression, and I have found that, all other conditions being the same, an animal lives five times as long in air of treble the density of the atmosphere as it does in the same volume of atmospheric air. It is remarkable that when the air is condensed to just about treble the normal density the animal falls into a condition of inactivity and lethargic sleep, which appears to be the result of pressure upon the brain. After this state has lasted for some time, the animal regains its natural activity; later it passes into a condition of extraordinary anxiety, which gradually increases until death. It is also noteworthy that the animal economy does not suffer from the compression. I have had birds for an hour in air reduced to one-quarter of its volume; on returning to air at normal pressure they quickly came to themselves and showed no signs of distress."

In 1808 Brizé-Fradin, who collected all the data known in his time, summed up the **disadvantages of diving-bells** as (1) ear troubles; (2) asphyxia from vitiation of the contained air by expired gases. He also adds that most physicians believe that the elasticity of the air acting in every direction and at every depth compresses the veins and the arteries, and causes (3) hemorrhages. In opposition to this view he adduces certain definite facts which seemed to him to destroy the hypothesis.

In 1820 Hamel descended in a diving-bell to a depth of about thirty feet in the harbor of Howth. He did not experience the slightest difficulty so far as breathing was concerned, but he suffered violent pains in the ears, which pains he likened to those produced by the abrupt introduction of a stick, and which were relieved when he swallowed the saliva in his mouth. He concluded from this that the diving-bell might be made use of in cases of deafness produced by obstruction of the Eustachian tube.

Colladon, in 1826, also remarked on these ear symptoms, and upon the means which were taught him by workmen for preventing them. "To remedy this difficulty, the workmen advised us to swallow our saliva after having tightly closed the mouth and nostrils, and to hold our breath for several moments; as a result the air within could act upon the Eustachian tube. My companion found but little relief in this manœuver. When we repeated it, he suffered much, he became pale, his lips lost their color, he almost became ill. His weakness was, no doubt,

due to the severity of the pain, together with the fear that he should not be able to bear it. Upon me the effect was quite different. I was in a state of excitement, just as if I had drunk some spirituous liquor. I did not suffer, but experienced only a strong pressure about the head, as though a ring of iron were firmly fastened there. While talking with the workmen I had some difficulty in hearing them; so much so that for three or four minutes I could not hear them at all. Indeed, I could not hear myself, although I spoke as loud as I could; and soon even the noise of the water against the walls of the bell failed to reach my ears. Finally we reached the bottom of the sea, where all disagreeable sensations ceased almost entirely. We breathed easily throughout the entire time we were under water. Our pulses suffered no alteration. Coming up we experienced quite different sensations from those of our descent. We felt as though our heads were growing larger and our bones were separating from one another. This sensation, however, was not of long duration." Colladon further says: "None of the workmen became deaf; it would rather seem that in certain cases the effect upon the ears served as a remedy for deafness. One workman, who ordinarily breathed with great difficulty, was completely cured soon after he began working in a bell."

Caissons.—Diving-bells are now out of date, but in bridge-building and similar subaqueous operations condensed-air apparatus called **caissons,** constructed after the method of Triger, are in daily use. Triger noted inability to blow when the air-pressure is very much elevated (three atmospheres); a nasal quality of the voice, becoming more marked with increase of pressure; and a tendency to dyspnea. Since caissons have come into general use we have learned their effects from exact medical observations. The accidents attending the return to diminished pressure, especially, have been studied with the greatest care. Concerning them we shall refer here to the writings of Pol and Watelle, Babington and Cuthbert, François, Bucquoy, Foley, Bauer, and others.

Pol and Watelle thus describe the **physiologic effects** observed in themselves: Pains in the ears, slowing of the respiration, diminution of thoracic expansion, slowing of the pulse (from 70 to 55), and increase of the urinary secretion. They attribute to the density of the surrounding air certain muscular movements and the inability to whistle which they experienced when the pressure was more than three atmospheres. At the moment when the pressure was reduced they experienced a sensation of cold and slight dyspnea, while the pulse-rate increased to 85. Pol and Watelle state the advantages that might be expected from compressed air for therapeutic purposes, and refer the bad effects to

their true cause. According to these authors, there is no danger in entering the caisson, nor in a more or less protracted exposure to increased pressure; decompression, or the return to standard air, alone is to be feared, and the workmen suffer only when they leave the caisson.

The **ill effects of decompression** referred to by Pol and Watelle are: respiratory embarrassment, amounting sometimes to distress; increase in the rate and force of the pulse; sharp muscular pains, the earliest and most constant symptom and one that may even take the form of permanent contraction or flaccidity; hebetude; loss of sensation; coma; deafness; sometimes blindness, which is very often permanent; and, lastly, sudden death. Young subjects are less susceptible than adults. Pol and Watelle have further noted the laky color of the venous blood which persists for some time after the return to standard air.

Babington and Cuthbert have given us a medical study of the effects observed during the construction of the bridge of Londonderry in 1861. They noted the effects of prolonged exposure to compressed air,—2.8 atmospheres,—but dwelt especially on the paralytic sequelæ.

Bucquoy, in a very important work, discussed the physiologic effects of compressed air observed during the construction of the bridge at Kehl. He admits that in compressed air the pulse is more rapid than in standard air, and that this is true of all degrees of compression, but especially of a pressure of 2.5 atmospheres. The increase of the respiratory capacity is constant. It continues to augment up to two atmospheres, and remains increased for a considerable time even after return to the normal atmosphere—which shows the efficacy of condensed-air baths for patients possessing but small vital capacity. Concerning respiratory combustion, Bucquoy thinks that it also is increased, but he does not consider the question definitely settled.

François, like Bucquoy, also studied the **pathologic effects** of greatly condensed air. In addition to pains in the ears, he frequently observed pains in the extremities and in the joints, accompanied sometimes by local swelling; pruritus ('the fleas,' in the slang of the workmen), and medullary disturbances, retention of urine, fractures of the extremities, and paralytic phenomena.

Foley studied the disturbances appearing in caisson-workers engaged in the construction of the bridge of Argenteuil. He noted vibration of the base of the cranium during speech, and a metallic quality of the voice. He believed these phenomena to be due to the flattening of the mucous membranes of the respiratory tract, making the oro-nasal and pharyngo-laryngeal cavities larger and of bony resonance. The voice is raised in pitch, because the increased tension of the air, necessary to

make it vibrate, causes a corresponding increase in tension at the margin of the larynx, the tongue, the lips, the soft palate, and even the nostrils. The diminution and the loss of taste are also due to the flattening of the lingual papillæ; the tactile sense is obtunded; the pulse rapidly becomes thready, as the *vis à tergo* in the veins soon begins to fail. The venous blood becomes redder, the increased pressure favoring the combination of oxygen with the blood; the pulmonary capacity increases and the movements of the ribs diminish; in spite of the sweating there is no thirst because of the large amount of water in the condensed air; hunger is increased because of the enormous combustion to which the tissues are subjected in consequence of the increased oxygenation and the more energetic muscular contractions.

Caisson-workers at first enjoy increased strength, vigor, and appetite. In the long run, however, the opposite effect is produced, and the workmen have no return of their vigor except when in the caissons, and after a certain time even the compressed air loses its effect. Paresthesia ('the fleas') rarely appears at a pressure of less than 2.5 atmospheres, but never fails to be present at three atmospheres; muscular and synovial swellings are occasionally observed. Foley attaches no significance to decompression (return to standard pressure), and sees no objection to a reduction of three atmospheres in three minutes.

We can only mention the memoirs of Croizette; Desnoyers (1864); Hermel (1863); Limousin (1863), who in a case of paraplegia attributed the bad effects to apoplexy of the spinal cord; and Barella (1868), who lays down rules for the duration of the process of decompression—ten minutes for each atmosphere.

As the number of accidents increased, and as the bad effects frequently terminated in death, so that the contractors were held responsible before the courts, Triger, the inventor of caissons, addressed a report to the minister (1866), which was submitted to certain engineers, who reported that it was relatively easy to prevent these accidents. The preventive means consisted in the use of woolen garments in the caisson, and the manipulation of the lift-lock, for which no uniform rule could be laid down. In this regard, common sense must indicate the proper method of procedure; that is to say, the stopcock should not be opened too quickly either in locking or unlocking, so that the organism may have time to adapt itself to the medium in which it is placed. Triger asserted that if seven minutes were allowed for the decompression, the accidents would cease to appear. It would seem, however, that this time varies with the constitution of the individual workman.

When the bridge at St. Louis was being built across the Mississippi,

Eads noticed paralytic sequelæ especially. The total pressure reached 4.45 atmospheres. Many persons, including women, visited the works, and no bad effects appeared among them—not more than among the workmen employed to close the doors. When the duration of working sessions was reduced to one hour, bad effects ceased to appear among the workmen. Eads therefore concluded that the rapidity of the compression and decompression is a less important factor in the production of accidents than is prolongation of the sojourn in the caisson.

Bauer emphasizes the fact that paralyses of different degrees are seen in grave cases. He found at autopsy "hyperemia of the spinal and cerebral meninges, edema of the arachnoid, and irregularly distributed areas of softening in the brain and spinal cord."

During the construction of the gigantic Brooklyn bridge Roebling noted that the respirations were reduced in frequency by 30 to 50 per cent., the organism reacting thus to the increased introduction of oxygen, as compared with that contained in the usual atmosphere.

The accidents very frequently observed in divers are quite comparable to those suffered by caisson-workers, and we may here refer to the memoirs of Leroy de Méricourt, who lays stress upon the paralytic sequelæ and upon the occurrence of sudden death, as do other observers. A. Gal, in addition to detailing the ear troubles and the changes in the pulse, respiration, and secretion, describes disorders of insidious onset—manifestations of a peculiar anemia. Cotronopoulos emphasizes the spinal cord lesions.

The facts that we have enumerated have more than an historical interest, for they afford us an opportunity of studying the numerous theories advanced by various writers to account for the bad effects which have been frequent ever since the discovery of Sturmius. These theories, sometimes bizarre and often contradictory, must be weighed and judged in order to strike the balance of our actual knowledge; for the basis of the therapeutics of condensed air—the only solid basis—must be a thorough knowledge of its physiologic and pathogenetic effects.

As caisson-working has latterly become more and more general, and the accidents we have related happen but occasionally, we have brought our historical note only up to a period dating back twenty-five years. At that time there was published a great work, from which we have drawn, and shall draw, largely. This work, the magnificent treatise of Paul Bert upon barometric pressure, marks one of the true turning-points in the history of science, when, by the light of laboratory experimentation, ideas are coordinated, observations are explained and correlated in orderly fashion, abstract theories are relegated to their proper subordination,

and truth is drawn from the chaos of conflicting hypotheses. Since these researches were published, the furrow has been widened, but the lines had been laid down; and while it is proper to render homage to the forerunners of the truth, the interest attaching to observations that confirm well-established knowledge is relatively slight. The summary that follows is based upon the more important of the contributions referred to.

PHYSIOLOGIC EFFECTS OF HIGH ATMOSPHERIC PRESSURE

When a human being or an animal is subjected to gradually increasing air-pressure, the following phenomena may be observed: At first there is an **exhilaration,** a stimulation of the general activity. As the pressure continues to increase, **pains** develop **in the ears,** the physiologic explanation of which simply is that the pressure within the tympanic cavity is less than that on the outside of the drumhead; the **voice** becomes **shrill** and acquires a **nasal twang.** When a pressure of three atmospheres is reached, speaking requires a great effort and it is almost impossible to blow or whistle.

So long as the pressure does not exceed five atmospheres, the other symptoms observed consist only in slight functional changes, and life remains quite possible under certain conditions that will be mentioned later. But if a pressure greater than five atmospheres is attained—which is rare both for caisson-workers and for divers, and has therefore been studied only in its effects upon animals—there comes a time when **life is extinguished.** While at a pressure of four or five atmospheres the animal does not appear to suffer any great disturbance, at six or seven atmospheres it manifests unmistakable signs of distress; it flounders about, moves from one side to the other, and acts, in short, as though it were trying to escape from its environment. At the same time the **respiration** becomes panting in character and the **heart-beats** are accelerated; the rectal **temperature** is slightly increased.

When the pressure reaches fifteen atmospheres, phenomena of central **nervous excitation** make their appearance, in the form of epileptiform seizures, repeated at variable intervals—often every five to ten minutes. These seizures reappear at shorter and shorter intervals and gradually diminish in severity until death takes place.* During the seizures and

* In all our statements in regard to the effect of variations in barometric pressure a liberal use has been made of the essay of Paul Bert as well as of the thesis of Guebhart, and especially of the remarkable article on barometric pressure contributed by Carvallo to the "Dictionnaire de Physiologie."

in the intervals between them the respirations are very deep and rapid. Under **very high pressure** death takes place in the first seizure. Sensation and mentality are not affected. The animal preserves its psychic and medullary reflexes and appears to be quite aware of the gravity of its situation. It is a surprising fact that the temperature, which rises to 40° C. (104° F.) under the influence of compressed air at a few atmospheres, subsequently falls rapidly when the pressure is raised to 15 or 20 atmospheres and is not again elevated. The subject of the experiment dies in a condition of true hypothermia.

What is the **cause of death** under these conditions? This is a subject that merits careful investigation. Death has been attributed to pressure alone, but it is necessary to be more precise.

Effects of High Pressure on Aquatic Life.—It was formerly believed that after a certain depth had been reached, animal and vegetable life came to an end under the water. It is known that pressure increases in proportion to the depth, ten meters of sea-water corresponding approximately to one atmosphere. It was formerly taught that at the depth of 400 meters, equivalent to 40 atmospheres, life was impossible (Forbes), but modern investigations have shown beyond a doubt that this is far from being true. John Ross proved the existence of animal life at a depth of 1500 to 1800 meters by means of a series of soundings in the Arctic Ocean; Clark Ross, in the waters about the South Pole, and Wallace, in the Atlantic Ocean, verified the truth of these statements. In 1865 Milne-Edwards had the opportunity of examining a fragment of the submarine cable which connected Algeria with Sardinia at a depth of from 2000 to 2800 meters, and found various species of marine animals attached to the cable, among them some polypi. Since then the investigation of the fauna and flora in the depths of the ocean has been carried on with equal perseverance and success by the 'Lightning,' the 'Challenger,' the 'Talisman,' and 'L'Hirondelle.' The Prince of Monaco devoted himself especially to the study of these questions, and it is now known that life exists at a depth of 4000 meters, which is equivalent to a pressure of 400 atmospheres. Life at these enormous pressures, however, is possible only for animals without lungs, the interior of whose bodies is in communication with the aquatic medium. P. Regnard in an able book published the results of his researches on the effects of great pressure on aquatic animals. Pressure acts by forcing the water into the tissues of the animal experimented with, a mechanism that finds its explanation in the fact that the protoplasm of the epithelial cells, the substance of the muscular fibers, and the myelin of the nerves are more compressible than the water on the one hand, and their coverings on the

other hand. The water pushes them aside and takes their place, as may be shown by histologic examination.

Effects on Life of High Atmospheric Pressure.—In the air the pressure limit at which vegetation and animal life become impossible is much lower than in water, 20 atmospheres being sufficient. The germination of seeds is retarded by increased pressure, and ceases when the pressure reaches a certain degree. At a pressure of two atmospheres a retardation of the germinative and vegetative processes in green plants becomes manifest; at five atmospheres the effect is marked; at seven atmospheres and over, the seeds merely throw out a few radicles, but no sprouts make their appearance. If the pressure is raised still more, neither germination nor sprouting takes place.

At a certain degree of compression, **putrefaction** in dead animal tissue is arrested and no bad odor is manifest. The gross appearance of muscles remains normal, and the structure of the fiber is not sensibly altered. Milk does not ferment. Brewer's yeast also is killed by condensed air, as is the mycoderm of wine and of vinegar. Without enumerating all the experiments of Paul Bert on ferments, pathogenic microbes, venoms, and the like, general conclusions may be presented, at the same time admitting that the experiments are not numerous enough in certain cases to be decisive, while the experimental technic is not beyond criticism.

In the case of the higher animals, insects, plants, and bacteria, the bare fact remains that life is impossible when the organism is subjected to a pressure reaching 20 atmospheres. It is therefore fair to conclude —and this is the reason why these facts, which apparently have little direct bearing upon our subject, have been insisted on—that the mode of action of the augmented pressure is identical in every case. Life, according to Paul Bert, is merely the result of a complex and harmonious assemblage of chemical modifications belonging to the group of fermentations: some are due to the direct intervention of the formed elements of the body; others are due to the action of unstable soluble substances analogous to diastase and preformed by the action of the formed elements. In the interior of each of these structural elements vital movements are maintained solely by the action of these substances which have their birth, exert their life energy, become transformed, and undergo destruction within these elements. But, for the maintenance of life it is necessary that the complex phenomena be carried on with a certain regularity, or rather with a constant harmony. When the intensity only is modified, without alteration of other relations, vital activity diminishes or may even become suspended for a considerable period, to

reappear when more favorable conditions have been reestablished. This is what happens under the influence of cold, of desiccation, and—to return to our subject—of **diminished pressure.** Seeds, which remain quiescent *in vacuo*, germinate when they are again exposed to the air. Meat, which remains fresh *in vacuo*, undergoes decomposition as soon as its bacteria are supplied with the oxygen necessary for their activity. When, on the other hand, not only the quantity but also the quality of the chemical changes is modified, disturbances supervene, of which our detailed knowledge is as yet but slight, and which are so far-reaching in their consequences that even if normal conditions be restored, vital activity is unable to reassert itself. This is what happens under the influence of heat, of excessive humidity, and of **increased air-pressure.** Seeds that have apparently been preserved intact under highly condensed air will not germinate when they are again exposed to normal pressure; and when the vibriones of meat have once been rendered inactive by exposure to condensed oxygen, it is useless afterward to supply them with oxygen at the ordinary pressure; their viability has been permanently destroyed.

General facts can be explained only by general laws, and it would be tantamount to disregarding the most elementary principles in the explanation of the action of high pressures, to attribute it solely to a direct mechanical action, a sort of crushing force on the part of the air, derived from its tremendous weight. Whether it will be necessary to modify this repudiation of mechanical action will be seen when we come to study the low degrees of pressure utilized in medicine.

CHEMICAL EFFECTS OF HIGH ATMOSPHERIC PRESSURE

A study of the symptoms observed during death in an animal subjected to high pressures demonstrates the presence of phenomena of a **toxic** character. The earliest observers noticed in caisson-workers the red color of the venous blood, and it is therefore logical to conclude that a **more active absorption of oxygen** * takes place in the lungs in condensed air. The phenomenon is certainly not due to the increased quantity of oxygen present. Regnault and Reiset have demonstrated that even when pure oxygen is breathed, the quantity of oxygen ab-

* Lazarus is not disposed to admit that any material qualitative or quantitative change in the 'respiratory metabolism' takes place in compressed air. He denies that the increased quantity of oxygen in the inspired air exerts any influence on the gaseous interchange. Instead of the oxidation processes being increased, as maintained by Bert, he affirms that a smaller quantity of oxygen is utilized, especially if the breathing is continued for some time.

sorbed is not increased. Another explanation therefore seems necessary, and it has been sought in a change of tension. Dalton's law of the interchange of gases appeared to furnish a clue, but Fernet, in his able work, had already resorted to experimentation, demonstrating that in the lungs the gaseous interchanges do not follow the law of Dalton. Under the inspiration of Bucquoy and Soley it was acknowledged that the red blood-corpuscles can absorb only a fixed amount of oxygen, and it was therefore believed that oxygen became dissolved in the blood-plasma; but this opinion proved to be erroneous. The solution of the problem was furnished by the experiments of Paul Bert. When an animal or a human being breathes in a medium in which the carbon dioxid cannot attain a tension high enough to become the direct cause of death, it is the oxygen, the vital gas *par excellence*, that brings on death. Oxidation —to speak somewhat paradoxically—kills in two ways: either by default (Lavoisier), or by excess (Paul Bert). From all the observations of Paul Bert the two following laws, the importance of which cannot be sufficiently emphasized, may be deduced: (1) The action of gaseous substances introduced into the organism of living beings by way of the respiratory passages is closely related to the individual tension of these substances in the respired medium. (2) If the tension of these gaseous substances be gradually increased, their action on the organism will not increase in proportion to the tension, but follows a course that is, generally speaking, somewhat more complicated. In the case of a gas or of gases necessary for the maintenance of life, there is always a certain tension (optimum) that is most favorable, ranging between a minimum and a maximum, above and below which the equilibrium on which life depends is put in jeopardy and finally destroyed. If an animal be subjected to an excess air-pressure of between one and two atmospheres, death will occur only after a prolonged exposure.

When the tension of the oxygen is too low, the increase in the tension of the **carbon dioxid** plays a certain rôle, which is, however, comparatively unimportant. Between two and nine atmospheres death takes place only when the tension of the carbon dioxid in the compressed medium reaches a certain degree, which is practically constant for each species of animal; but above three or four atmospheres the **toxic action of oxygen** makes itself felt. Above ten atmospheres, carbon dioxid plays no part whatever in the causation of death, the tension of the gas becoming feebler and feebler in proportion as the total pressure is raised. Intoxication is due to oxygen alone, as is proved by the experiments of Paul Bert, which have been confirmed repeatedly. The practical point to be borne in mind is that in comparatively low pressures, not exceeding

two atmospheres in ordinary cases, the toxic action of oxygen need not be feared.

On the other hand, whenever the **pneumatic chamber** is employed and the sittings are protracted for any length of time, care must be exercised that (1) the tension of the oxygen shall not fall below a certain point, equivalent to about one-fourth of what it is normally in atmospheric air, and (2) that the tension of carbon dioxid shall not rise above a certain point, which for the sparrow is equivalent to one-third of an atmosphere.

ACCIDENTS OCCURRING DURING DECOMPRESSION

Before considering the pressures utilized in medicine it will be necessary to say a word in regard to the accidents that are apt to occur during the stage of decompression. In divers, who are subjected to excessive pressures, the discomfort begins at the bottom of the water and must be attributed to the pressure alone; so that the accidents that are observed appear to be due to the causes which have just been enumerated. In the case of caisson-workers, on the other hand, a pressure of four or five atmospheres is rarely exceeded, and most of the accidents occur when the workman leaves the caisson; hence they are described as **accidents of decompression.** In addition to the special interest that attaches to the study of decompression accidents in general, we have that which results more immediately for us from the researches of Philippon, who demonstrated that these accidents may occur even with low pressures if the decompression be too rapid.

Certain pathologic phenomena have been observed to occur in men who work in diving-bells and in caissons, and in divers when they pass too rapidly from compressed air to the normal atmosphere. These accidents consist in an intense **pruritus** (**'puces,'** 'fleas'); the appearance of **muscular tumors** (**'moutons,'** 'sheep'); **swelling of the joints**; various **sensory disturbances**; **paralyses,** often unilateral and chiefly paraplegic; and sometimes **sudden death.** The minor symptoms soon subside, but the paralytic phenomena are more lasting, and in some cases even incurable. Paul Bert has made some experimental studies upon these facts, and was first struck with the unequal resistance observed in different species of animals; thus, a bird resists a decompression of ten atmospheres, while in mammals the accidents occur at six atmospheres, and at a pressure exceeding nine atmospheres death is the rule. But even among mammals there are certain differences, the rabbit being less susceptible than the cat or the dog. Marked differences are sometimes observed in individuals of the same species; young dogs, for instance, are more resistant than full-grown animals. In animals that

have resisted the effects of sudden changes of pressure for a number of days, certain changes are observed at the autopsy, consisting chiefly in softening of the spinal cord, which attains its maximum in the lumbar enlargement. Bouchard advances a theory, which, however, is not upheld by the facts. It is that hemorrhage takes place at the moment of decompression because the intestinal gases, regaining their original volume and distending the intestinal walls, bring about in the abdominal organs a positive pressure in the opposite direction that expels the blood stored up in their interior and suddenly throws it into other organs whose vessels have lost their tone and are unable to accommodate themselves at once to this sudden invasion of blood. It is in this way, he asserts, that epistaxis, hemoptysis, and sometimes evanescent or fatal apoplexies are produced, accompanied in certain cases by momentary or permanent hemiplegia, and finally by those transitory or permanent paraplegias described by M. Barella in the case of laborers working in shafts or caissons, and which, according to M. Leroy de Méricourt, constitute the commonest cause of death among sponge fishermen. Bouchard's premises are faulty; for the expansion of the intestinal gases never exceeds a moderate degree and pulmonary and cerebral hemorrhages are exceptional occurrences.

Pol and Watelle suspected the true cause, and Bucquoy and Hoppe-Seyler went so far as to state it, but only as an unverified hypothesis. It is the **escape of the gases from the blood** and their return to the free state under the influence of sudden decompression. The liberation does not affect the three gases of the blood equally; the proportion of oxygen is very little increased as the pressure is raised; that of the carbon dioxid undergoes no increase whatever, and it is therefore logical to incriminate the **nitrogen.** Paul Bert succeeded in extracting the gases contained in the heart, and found them to be composed chiefly of nitrogen, with a small quantity of carbon dioxid probably introduced along with the current of nitrogen. The danger lurks in the nitrogen, since carbon dioxid and oxygen are rapidly dissolved if necessary. It is probable that all the excess of nitrogen escapes in a free state. Now, Paul Bert tells us that at ten atmospheres there is an excess of about 8 cubic centimeters of nitrogen in 100 cubic centimeters of blood. Supposing that a dog weighing 14 kilograms contains one kilogram of blood, it follows that 80 cubic centimeters of nitrogen and about 20 cubic centimeters of carbon dioxid are thrown into the arteries and veins—a quantity quite sufficient to bring about immediately fatal results. What takes place, then, at the moment of rapid decompression when gas in large quantities is liberated in the veins, the arteries, the portal system, and

even in the placental vessels in pregnant animals? The left heart forces its gaseous content back into the arteries, and the right heart, which receives a large quantity of gas from the veins (33 cubic centimeters in a cat), throws back a sanguineous, frothy mass into the lungs. Now, the experiments of Jamin have shown that an enormous pressure is required to force a column of liquid separated by minute columns of air through a system of capillary tubes—a fact that may serve to explain the phenomena of asphyxia and black discoloration of the arterial blood observed in certain cases. It likewise explains why the decompression accidents do not supervene at once, but usually require from five to fifteen minutes for their production. The liberated nitrogen is too sparingly soluble to be rapidly dissolved and, on the other hand, its tension in the lungs is not sufficient, as compared with the tension of the nitrogen in the inspired air, to cause it to be expelled. Hoppe-Seyler, Haller von Hallenstein, and Zuntz have since confirmed the investigations of Paul Bert in all their particulars.

A point of special interest is the fact that **paralysis** in almost every case begins in the **lower extremities.** Why is the lumbar enlargement of the spinal cord affected first and more often than any other portion? Paul Bert discovered the presence of gases not only in the veins and in the cavities of the heart, but also, with the aid of the microscope, in the capillaries of the nervous centers. The phenomena known as 'fleas' and 'sheep' (pruritus and muscular tumors) are due to the same cause as the paraplegia and sudden death. They are expressions of the local irritation of the tissues by the presence of free gaseous bubbles in the capillaries. The experiments of Feltz, carried out for the purpose of controlling the much older ones of Bichal and Nysten, throw a clearer light on the details of the mechanism concerned in the production of these accidents. He found that, comparatively speaking, enormous amounts of air, 750 to 1200 cubic centimeters (say a quart), could be injected into the veins at the rate of 50 cubic centimeters every ten minutes, without producing any more serious disturbance than a slight acceleration of the respiration, and without bringing on any nervous trouble suggesting arterial embolism. When the air is injected rapidly, a momentary syncope is produced; but to bring on death by cardiac paralysis requires very much larger doses. The injected air does not pass into the pulmonary veins or into the arterial system. The results are quite different, however, if air is injected into the arteries—a procedure which produces accidents comparable to those observed during decompression. Injection of air into the descending aorta is followed by paraplegia; if air is injected into the carotid, death ensues;

if into the branches of the carotid, various forms of paralysis result and bubbles or traces of air are found in the capillaries, where they produce total arrest of the blood-current. This may explain the frequency of paraplegia. The development of gas in the aorta is followed by the production of gaseous emboli that do not induce any grave disorders in the lower extremities, but do bring about marked changes in the spinal cord by reason of the arrangement of its capillaries.

It is thus evident that the **intensity of the accidents** occurring during decompression depends on several factors. These are:

1. The **length of the exposure to compressed air,** a matter of common observation in the case of caisson-workers and divers.

2. The element of **individual resistance,** which Paul Bert mentions without volunteering any explanation; so that the latter still remains to be discovered. In the case of birds, Campana attributes the increased resistance to the air-sacs in which the gases can accumulate. But in comparing the resistance of individuals of the same species a different reason must be sought. Carvallo appeals to the individual variations, discovered by himself, in the coefficient of absorption of gas in the blood, and to the fact, demonstrated by Feltz, that certain individuals possess a greater power than others of eliminating gas through the lungs.

3. The **degree of pressure attained.** Paul Bert believed that decompression became fatal only when the pressure had reached five atmospheres; and this is true, provided decompression be effected gradually.

4. The **rapidity of decompression.** By means of an ingenious apparatus Philippon demonstrated that, if decompression were effected rapidly (in ten seconds), death might be induced in animals submitted to a pressure that may be described as insignificant. From the viewpoint of medicinal aërotherapy, therefore, the greatest stress is to be laid on the facts revealed by a study of the accidents that occur during decompression. Paul Bert advised that decompression be effected at the rate of from eight to ten minutes for each atmosphere, but some authors go further and double the period advised.

Treatment.—When accidents occur, the only way to combat them effectually is by **restoring the pressure** to its former height; either immediately, or, if murmurs be heard in the heart, after the **administration of oxygen.** The inhalation of pure oxygen serves the purpose of facilitating the diffusion of the nitrogen, as the inspired gas contains no nitrogen and the tension of the nitrogen contained in the blood is enough to effect its escape. But this procedure is of use only when nitrogen has accumulated in the right heart and in the lungs. To dispel the bubbles of nitrogen that arrest the circulation in the capillaries or those

that are disseminated through the tissues, recompression is the only trustworthy means. The **prognosis,** according to Bert, must always be doubtful, because the bubbles of gas, in regaining the free state in the interior of delicate tissues like those of the spinal cord, may produce certain disturbances or even lacerations, the evil effects of which do not disappear after the dispersion of the gases.

PHYSIOLOGIC ACTION OF MODERATE EXCESS PRESSURES

Historical

The first observations of any importance on the effects of moderate increase of air-pressure were published by Junod, who showed that when the natural pressure of the atmosphere is augmented by one-half, the following effects will be observed: (1) A disagreeable sensation of **pressure in the ears** is experienced, subsiding as equilibrium is re-established. (2) **Respiration** is facilitated. The capacity of the lungs for air appears to be augmented; the inspirations become deeper and less frequent. After fifteen minutes an agreeable sensation of warmth is felt in the interior of the thorax; there is a feeling as if the pulmonary alveoli had been contracted for a long time and were being changed by contact with the air—suddenly becoming widely dilated to receive it, while the whole economy is taking in fresh air at each inspiration. (3) **Circulatory** and resulting **innervational** changes occur. The pulse manifests a tendency to increased frequency, it is full and easily compressible; the caliber of the superficial veins is diminished, and the lumen may even become completely obliterated, so that the blood on its way back to the heart courses through the deeper veins. If the caliber of the superficial vessels diminishes or increases on account of the elastic tension of the atmosphere, the same effect must necessarily occur in the pulmonary vessels, which are similarly affected by changes in the atmospheric pressure. It follows therefore that, the pressure of the air being augmented, the quantity of venous blood contained in the lungs must diminish; and this probably explains why a much greater quantity of air can be drawn into the lungs at each inspiration than is possible under normal pressure. Further, if an increase in the density of the air tends to diminish the caliber of the veins, it follows necessarily that a greater quantity of blood will enter the arterial system and more blood will also reach the principal nerve-centers; especially those in the brain, because the latter is protected from the direct pressure of the atmosphere by the resistant bony calvarium. The cerebral functions are accordingly enhanced, the imagination becomes more active, and in some persons there is a peculiar

exaltation which simulates drunkenness. The innervational increase affects the muscular system also; movements are performed more easily and with greater precision. (4) The functions of the **digestive apparatus** are stimulated and thirst is abolished. (5) The **secretion** of the salivary glands and of the kidneys is very profuse.

In 1838, after experimenting for a number of years, Tabarié published a monograph in which he discussed the effect of general condensation of the air on the economy; the effect of local condensation on the limbs; the effect of local alternate or undulatory condensation and rarefaction on the limbs; and the effect of rarefaction on the entire body except the head. In 1840 he studied more particularly the action of compressed air, and found that it retards the action of the heart and steadies the rhythm. This effect is very slight and may not be noticeable under normal conditions, but becomes quite evident in disease. He also found that compressed air has a tendency to moderate stimulation of heat production. Moderate pressure, not exceeding $+ \frac{2}{5}$ of an atmosphere, gives better results than a higher pressure of, say, $+ \frac{4}{5}$ of an atmosphere.

Pravaz, in 1837, observed that the arterial circulation was not greatly modified by the compressed-air bath when the individual had a strong constitution and was in good health; but when there was morbid acceleration of the pulse, the latter was found to be materially retarded. Capillary injection of the skin and mucous membranes becomes greatly diminished, the phenomenon being most marked in conjunctivitis and at the site of a blister. The appetite may be stimulated to the point of bulimia; the urine is increased in quantity and materially changed in quality, which is a logical result of the increased activity in the metamorphosis of the tissues that follows a greater absorption of oxygen. The good effect on the breathing is most marked in invalids suffering from chronic dyspnea. Milliet, in 1854, confirmed the observations of Pravaz on the retardation of respiration, and also noted a retardation of the pulse. Sandhal, in 1862, noted in a general way a diminution in the number of respiratory movements, not only during, but also after the baths. The frequency of the pulse was also diminished. Tutschek, in 1863, practically confirmed the findings of his predecessors.

Lange sums up the facts as follows: Slowing of respiration and circulation; very probably increased absorption of oxygen by the skin and lungs; increase in the amount of carbon dioxid exhaled; diminution of cutaneous transpiration and pulmonary exhalation; increase in urinary secretion and elimination of uric acid; diminution in the elimination of urinary phosphates.

Von Vivenot, in 1860, began a series of publications on the subject under discussion, and in 1868 condensed them in a single work which may justly be described as one of the most exact and best arranged in the literature of pneumotherapy. He carried out most of his experiments in the Institution at Johannesberg with an excess pressure of $\frac{3}{7}$ of an atmosphere. We cannot do better than quote his conclusions in full:

An unpleasant sensation is felt in the ears. The voice becomes higher in pitch, articulation difficult, and whistling quite impossible; sometimes slight stammering is noted. Smell, taste, and touch become less acute. Negative pressure during inspiration, and positive pressure during expiration, are increased. On account of the compression of the intestinal gases the convexity of the abdomen diminishes, and the diaphragm and base of the lungs become depressed; the lung during both inspiration and expiration overlaps the heart. The cardiac impulse is accordingly diminished in force and the heart-sounds are feeble on auscultation. The effect upon special systems and processes is described about as summarized in the paragraphs following:

Respiration.—The **pulmonary capacity** increases. At a pressure of $+\frac{4}{7}$ of an atmosphere an average increase of 73.40 cubic centimeters (4.47 cubic inches) was noted in half-an-hour, and an increase of 105.27 cubic centimeters (6.42 cubic inches) at the end of an hour and a half; or, in other words, an increase of 3.30 per cent. of its original volume in the subject of the experiment. When normal pressure is re-established, this increase is in part lost, but the lung does not quite recede to its original volume. After repeated séances the pulmonary capacity continues to augment every day, but the increments are greater at the beginning than toward the end of the treatment. After a three-and-a-half months' course of air-baths von Vivenot found that his pulmonary capacity had become one-fourth greater, although no loss was observed in the contracting power of the lung. The **habit** acquired by the diaphragm and thorax persisted after the experiments were discontinued. The enlargement of the pulmonary capacity is observed not only during abnormally active respiration, but also during ordinary breathing, and the diaphragm also descends to a lower level than under normal conditions. Respiration becomes less frequent; the number of movements diminishes from one to four in the minute. This phenomenon persists for some time after the individual has returned to standard air. Inspiration is more rapid, expiration slower. The first portion of expiration is somewhat abridged, and the second portion is so slow that there appears to be a pause.

Metabolism.—The proportion of **carbon dioxid** contained in the expired air increases. One respiration at the pressure of $\frac{3}{7}$ of an atmosphere above normal yields on the average 22.26 per cent. more carbon dioxid than a respiration at ordinary pressure. There is therefore no exact relation between the excretion of carbon dioxid and the gain in the capacity of the lungs, which amounts to 3.3 per cent. The increase in carbon dioxid takes place not only during forced respiration, but also during ordinary breathing. Comparison with the diminution in the respiratory rate shows that an absolutely greater quantity of carbon dioxid is given up in a unit of time, and therefore a greater quantity of oxygen is absorbed. In consequence, after a prolonged exposure to condensed air the venous **blood** appears brighter in color; the **body-temperature** is increased by 0.1° to 0.4° C. (0.2° to 0.7° F.); muscular strength is greater; the appetite is sharpened and the **body-weight** diminishes on account of the increased combustion, in spite of a more abundant diet. If, however, the pressure is not excessive and a good deal of nourishment is taken, the body-weight may later be increased.

Circulation.—The frequency of the **pulse** diminishes from 4 to 7 beats in the minute; the diminution is proportionally more marked when an abnormal acceleration has been present. When the individual returns to normal atmospheric pressure, the pulse regains its normal rhythm. If, however, an abnormal frequency of the pulse has been due to some respiratory disturbance, a permanent slowing may result from treatment with compressed air. This effect appears to be purely mechanical. The increased pressure on the surface of the body augments the resistance encountered by the blood-waves propelled during cardiac systole, the action of the heart accordingly becomes more labored, and the number of pulsations diminishes. The curve of the radial pulse shows certain modifications: the height of the stroke diminishes, the upstroke is less abrupt (more oblique), the apex is rounded, and the downstroke loses its wavy character, becoming straight or slightly convex. The caliber of the vessels—and consequently the quantity of blood which they contain—is therefore diminished; while there is an increase in the resistance to the systole of the heart, and some interference with the movement of the blood in the capillary circulation. Return to standard air is followed by the reappearance of the original pulse-tracing. The change in the radial pulse may be perceived by the sense of touch; it becomes small, thready, and can barely be felt.

The strength of the **heart** is not increased in compressed air; nor is there positive knowledge whether it is diminished. While the air-pressure is rising, the sphygmographic curve is higher than that obtained at

normal pressure; hence there must be, during this phase, an increase in the total pressure of the blood, at least in the radial artery.

Experiments performed on animals to determine the **pressure of the blood** in the carotid artery by means of the hemodynometer were not conclusive. It is probable that when the pressure of the air has become constant, a second stage of equilibrium is reached; and when the action of the heart is weakened, a corresponding diminution of tension occurs in the arterial system. The diminution in the caliber of the conjunctival and retinal vessels, and of the vessels in the ear of a rabbit; the discoloration of the pupil and of the iris in white rabbits; and the pallor of men working in compressed air, directly prove that the blood is dammed back from the periphery to the center. To this process must be attributed the diminution in intraocular pressure; the contraction of the pupil; the diminished force of the pulse in the ear and in the jaw; the pallor of the tympanic membrane; the improvement observed in cutaneous affections; and, finally, the disappearance of scrofulous struma.

No direct experiments have been made to learn the influence of compressed air on the **venous** and **lymphatic** systems, but there is no doubt that the effect is excitant, and the increase of negative pressure in addition acts on the heart and large blood-vessels. It has been shown by means of a manometer introduced into the jugular vein that venous pressure diminishes in compressed air. (Von Vivenot, however, did not investigate this question personally. He refers to an experiment of Farnum which he admits to have been imperfect in technic and which cannot be regarded as decisive.)

The axillary **temperature** begins to rise as the pressure of the air is increased and reaches its maximum when compression is complete. During the stage of constant pressure there is also an increase in the rectal temperature.

It follows from these observations that a portion of the blood is driven away from the periphery of the body; the organism has therefore at its disposal a certain amount of blood that has been driven into the deeply situated organs, as the brain, the marrow of bones, the muscles, the intestinal tract, the kidneys, the liver, the spleen, and the uterus. This reflux of blood explains the various symptoms: The feeling of heaviness in the head with a slight deafness and tendency to yawn, resulting from the cerebral congestion; the intestinal symptoms, which take the form of hunger and a rise in the rectal temperature; the effect on the muscles, manifested by an increase of vigor and a rise in the axillary temperature; and the stimulation of the kidneys, which leads to the secretion of an increased quantity of urine. These complex symptoms, which are, in

addition, affected by the external cold, do not overstep the limits of physiology. Von Vivenot likewise states that no serious disturbance in the circulation of the blood occurs, even when the pressure is raised to four-and-a-half atmospheres. On the other hand, during the stage of **decompression,** troublesome and even dangerous effects may be produced if the pressure be reduced too rapidly. Among these dangers are congestion, hemorrhage, pain, and especially disturbances of the equilibrium in the circulatory system. A grave accident that sometimes occurs is the development of gas in the blood, bringing about arrest of the circulation and sudden death. This accident must be combated by an immediate return to compressed air.

It will suffice to make brief reference to the chief conclusions of other experimenters. Freund observed an increase in his own pulmonary capacity which persisted five months after the termination of a course of thirty séances. Farnum observed the same phenomena, consisting in slowing of the respiratory movements and augmentation of the pulmonary capacity, both during forced respiration and during quiet and slow breathing. He found, however, that the relation between the length of inspiration and expiration is the same in compressed air as under normal pressure. He noted a slowing of the pulse-rate and a diminution in the velocity of the blood, indicated by the disappearance of toothache. G. Liebig observed an increase in the depth of the respirations with a slowing of the rate at an excess pressure of 72 or 73 centimeters (0.9 atmosphere). Meyer finds that the pulse is slowed. Marc insists especially on a diminution in the number of cardiac pulsations and augmentation of the pulmonary capacity. His observations were made on a colleague who was emphysematous, and suffered from attacks of asthma and hemoptysis. The work of Paul Bert has been referred to, and will again be discussed. His results have been much debated and criticized, and in this connection consideration will have to be given to the studies of Hadra, A. Fraenkel, Suchorski, Loewy, Bliden, Simonoff, Hoffmann, Knauthe, Lazarus, and others, as will appear in the next chapter.

To review the opinions we have just cited would accomplish no good purpose, since they do not agree as to the causes of the phenomena observed and are not entirely concordant even as to the phenomena themselves; and this is unfortunately the sole result of our long historical introduction. A brief résumé will therefore be made of the actual state of the question, reserving for later consideration a reconciliation of the contradictions upon questions that are apparently simple, although in reality quite complex.

EFFECTS OBSERVED IN THE PNEUMATIC CHAMBER

An individual placed in a pneumatic chamber passes through **three stages**: (1) that during which the pressure is **gradually raised** to the desired point; (2) that during which the pressure remains **stationary**; and (3) the **stage of decompression,** during which the pressure is **gradually reduced** to normal. In calculating the time required to pass from normal pressure to the desired increase and back again to normal pressure, the effects of both compression and decompression, and the conditions arising from the **temperature** and the **humidity** of the atmosphere under such conditions, must be taken into account. We ought perhaps first to enumerate the changes that take place within the organism, and then discuss their pathogenesis; but this would involve us in numerous repetitions. We shall therefore not again refer to the earache, having already given the explanation which is generally accepted. **Earache** and the **general sense of comfort,** which is more or less marked, constitute the only **subjective symptoms** noticed by the patients in the pneumatic chamber.

Mode of Action of Condensed Air

How, then, does the pressure act? On this point there is a great diversity of opinion. Some authors point to the pallor of the skin and the mucous membranes, the diminution in the volume of the pulse, and other symptoms, and assume that the air effects direct compression of the surface with which it comes in contact. In other words, they assume a purely **mechanical action.** Among the supporters of this view are Pravaz, Bucquoy, and v. Vivenot. Many others have accepted the theory advanced by Foley, that compressed air flattens the entire mucous area of the body. Bucquoy, who is better informed in regard to the laws of physics, declines to accept this explanation, and adopts the theory that the pressure progressively diminishes from the skin toward the deeper tissues—a theory that even at the present time boasts a number of champions; among them Knauthe, who contends that the modifications of pressure continue to affect the lung during the entire period of time necessary for the change in pressure to extend to all the cells of the organism. Reitlinger, professor of physics in Vienna, regards this theory as entirely tenable. The effect produced by a force of any kind requires for its completion a certain period of time, and the full change of pressure does not act equally on all parts of the body from the outside, the effect being first exerted on the parts in immediate contact with the air—namely, the lungs and the skin. In these portions of the

body an immediate change of pressure is produced; but it requires some time for the consequences of this change to reach the deeper portions of the body. It follows, therefore, that under the influence of compressed air the **skin is compressed** and the **lungs are dilated.** This partial action disappears as soon as the increase of pressure has spread to all the cells of the organism. Thus, the symptoms of mountain-sickness subside spontaneously so soon as equilibrium has been restored and the organism has completely adapted itself to the new conditions of pressure. Knauthe, however, does not believe that the time ordinarily passed in a pneumatic chamber suffices for the equilibrium of pressure to be reached; and thus explains the continued effect of the procedure. Among other **mechanical theories** are those of Junod, of G. Lange, of Leroy, and of Méricourt, in which it is assumed that there is a congestion of blood in the brain, which itself is protected by the cranium and cannot therefore be directly compressed. It is true, as Paul Bert has said, that these explanations find a certain measure of excuse in the complexity of the human body; but it is rather remarkable that they should have been accepted as confirmed by apparently decisive experiments.

There remain two features of the theory of mechanical action to be discussed, and they are not without importance: the **effect on the interior of the thorax,** and the **effect on the abdominal gases.** Caisson-workers are obliged to tighten their belts after they have entered the caisson, from which fact Pravaz concludes *à priori* that the action of the diaphragm is embarrassed and that the expansion of the thorax in a vertical direction is diminished. As a matter of fact, the direct opposite of this is true. All the authorities, and von Vivenot in particular, have demonstrated that the lungs descend lower in condensed air than under normal pressure. An experiment performed by Farnum is often quoted. It is as follows: A bladder half filled with air having been immersed in water, a second bladder provided with a tube is placed on top of the first one, the tube passing through a stopper which hermetically closes the bottle containing the two bladders. The bottle is therefore filled with water except for the space occupied by the bladders. The lower bladder represents the intestinal tract and its gases; the upper, the lung and trachea; while the bottle and the water it contains represent the closed thoracic cavity. If this simple apparatus be introduced into a condensed-air chamber, the lower bladder will be seen to diminish in volume while the upper one enlarges. The result of the experiment is not altogether changed if the bottle employed is closed below by an elastic membrane instead of a solid bottom. The closed bladder then acts as in the first experiment, but only part of the space made vacant by its

diminution in size is occupied by the upper bladder; the membrane rises. This shows that the compression of the air contained in the intestinal tract is the cause of the increased capacity of the lungs and the greater depression of the diaphragm. The experiment, according to Paul Bert, has one fault,—it accomplishes no good purpose; for we are interested not in knowing what happens within the abdomen in such a case, but rather in finding out to what extent the diaphragm and the abdominal walls tend to retract and occupy the space before held by the intestinal gases which have become diminished in volume. But on this point Farnum's experiments tell us nothing.

The **chemical theories** are scarcely more convincing. Brizé-Fradin was the first to suggest an increase in the absorption of oxygen, and numerous analyses by v. Vivenot and Farnum have been held to confirm the view. Nevertheless this mode of action of compressed air must be denied, for v. Vivenot made his experiments under the worst possible and altogether exceptional conditions. He analyzed the air of a single expiration at the rate of 3.76 respiratory movements a minute.

Are we, then, to accept without reservation the physical theory of the **instantaneous transmission of pressure** in every direction? We find in the thesis of Guebhard, written while the impression of Paul Bert's work was still recent, the following lines: "Our body is not a Pascal vessel; the liquids which it contains are neither homogeneous nor free in their movements, the pressure is not transmitted by a rigid piston but by a soluble and compressible atmosphere, and, finally, the existence of a cardiac center exerting control over elevated pressures brings about a dynamic state in which the first law of hydrostatics—that the surface of a liquid is always horizontal—is openly violated. It seems to us, therefore, that a large measure of reserve is necessary in the consideration of this problem, and there is danger of perverting its nature by attempting to reduce it to terms of an impossible simplicity. It must not be forgotten that the elementary study of the distribution of pressure in moving liquids is one of the most complicated problems presented in mathematical analysis, and the term 'instantaneousness'—a word devoid of all scientific meaning and capable of betraying one who uses it into the most absurd errors by an apparently logical train of reasoning —is not to be used lightly in stating an hypothesis." The experiments of Regnard on the effects of high pressure on aquatic animals have not been cited without a purpose. Although the interior of the body in these animals is freely open to the passage of water, and the pressure must, therefore, be transmitted in every direction, it has been observed that they swell on account of the water penetrating into the tissues, and the con-

clusion appears inevitable that the myelin, the substance of the muscular fibers, and the protoplasm of the epithelium are more compressible than the enveloping tissues. If, then, it is impossible to elucidate the law governing the transmission of pressure, we can at least agree on the fact of **unequal pressure**—which in any case is very small—on the various cellular elements of the organism, and—to go a little further—even on the different parts of these elements. With this reservation we believe that, with the low pressure employed in therapeutics, all the phenomena can readily be explained if it be remembered that the nervous system of the subject of the procedure frequently intervenes and modifies the results. Indeed, **nervous reaction** claims a large share in the true explanation of the apparently incomprehensible contradictions we meet in studying questions that on the surface appear to be easy of control.

Effect on the Lungs

We shall not return to the discussion of the theory of collapse of the pulmonary vessels, which has been sufficiently refuted elsewhere; nor shall we make much of the enlargement in the capacity of the thorax following an increase of internal pressure, for this is counterbalanced by the equal external pressure—and on this point also the mere enunciation of the law of the transmission of pressure suffices to close the discussion. The thoracic cavity can enlarge only in a vertical direction by means of depression of the diaphragm. Observation, however, reveals certain important facts concerning the respiratory process, which must be passed in review; after which an inquiry will be made into their possible explanations. The changes observed in respiration affect the **frequency** and **amplitude** of the respiratory movements, the **intrapulmonary tension,** and the activity of **oxidation** processes.

The number of respirations in a given period—in other words, their **frequency**—has been observed by most authorities to undergo a **material diminution.** Paul Bert alone, while admitting the difficulty of estimating one's own frequency of respiration, failed to note any distinct modification. In the animal, however, he has found that respiration was distinctly retarded. Aron has since then confirmed this observation in man by means of the plethysmograph. There is at the same time a change in the respiratory **type**: expiration is prolonged, while inspiration maintains its normal duration. Some authors assert that inspiration is even abridged, but the observation is hardly trustworthy.

The **amplitude** of the respiratory movements **increases** as a result of the increase in the pulmonary capacity. While the value of pulmonary ventilation in quiet breathing varies little (Paul Bert), all agree that a

considerable **increase of the maximum pulmonary capacity** takes place. In one case forced expiration ranged from 3.45 liters to 3.99 liters—in other words, there was an increase of 6.9 per cent.; and in another case the increase was even greater, namely, 11 per cent. It is to be noted, however, that the increase in the capacity of the thorax does not bear a constant relation to the increase in pressure; hence the **coefficient of pulmonary ventilation** cannot be increased, since the increase in the amplitude is accompanied by a synchronous decrease in the number of respiratory movements.

Intrapulmonary pressure also undergoes modifications, as appears from the pneumographic tracings, which show a diminution in the number of respiratory movements from ten to seven, and also show that the variations in intrathoracic pressure are much less in compressed air than at normal pressure.

Absorption of Oxygen and Elimination of Carbon Dioxid.—A considerable **increase** in the elimination of carbon dioxid was noted by Farnum, who studied the interchange of gases during respiration, and by Hervier, who was the first to study the phenomenon in the pneumatic chamber of Pravaz, and based his calculations on much more numerous and accurate observations. Up to two atmospheres, the activity of the organic processes of combustion increases but slightly, as shown by Paul Bert, who found that the same variation took place in warm-blooded and in cold-blooded animals. In a rat weighing 360 grams and accustomed for ten days to living in the bell-jar without ventilation, the results in regard to the consumption of oxygen and the production of carbon dioxid were as follow:

	Oxygen Consumed (Liters)	Carbon Dioxid Produced (Liters)
At 1 atmosphere,	12.6	7.06
At 2 atmospheres,	13.72	10.32
At 4.2 atmospheres,	11.35	6.96

Pol, François, and Foley report that the venous blood of caisson-workers is bright red. Suschorski found that the absolute quantities of **oxygen** absorbed and carbon dioxid expired were less than at normal pressure, even though the quantity of oxygen consumed was less than that of carbon dioxid eliminated. Loewy, in one series of six cases that he studied, was unable to establish any change in the quantity of oxygen absorbed, while in six other cases the quantity was found to be greater than at normal pressure. The same amount of work performed in compressed air and under normal pressure requires the same consumption of oxygen. Individual variations in regard to the affinity of hemoglobin for oxygen and the relations existing between the quantity of oxygen

in the blood and the quantity utilized in the tissues must also be considered. According to Loewy, the quantity of oxygen consumed depends solely on the activity of the cellular elements themselves.

Effect on the Circulation

The modifications in the circulation include the frequency of the heart-beats; the arterial tension and its respiratory oscillations; and, finally, the capillary circulation.

The **frequency of the heart-beats** is distinctly **diminished.** On this point all observers, with the exception of Junod, François, and Bucquoy, are agreed, and it must therefore be regarded as established.

Concerning the **pressure of the blood,** Liebig experimented for some time on a number of individuals of different ages, using an apparatus constructed on the same principle as Mosso's sphygmomanometer and Marey's sphygmoscope, and discovered a diminution of about 11 millimeters. Paul Bert, however, as a result of accurate observations on the arterial tension based on a number of manometric measurements, concludes that the pressure of the blood—and this includes the maximum, the minimum, and the mean pressure—is increased during sojourn in condensed air. The respiratory oscillations in blood-pressure are likewise materially increased in condensed air. The contrary results of v. Vivenot are based on observations of emphysematous subjects, and are therefore to be disregarded in a physiologic study. The variations in blood-pressure accompany a slowing of the respiration. Lazarus and Jacobson experimented with low air-pressures on rabbits and sheep, without anesthetizing the animals. In 11 experiments, performed under the most rigorous conditions, they obtained identical results, showing that diminution in blood-pressure never takes place, but that the increase is variable and inconstant. The same conclusions were reached by means of the sphygmomanometric method of Zadek.

A parallel study of the **rapidity of the circulation** is interesting in connection with the blood-pressure. The latter may remain unaltered, although the rapidity of the circulation increases or diminishes in accordance with the activity of the heart and the resistance encountered in the circulatory apparatus. Liebig and Loewy gave much attention to this problem, which had before been attacked by v. Vivenot. The results of Liebig's experiments, performed on four young dogs, indicate that the velocity of the circulation is not altered. In two cases he found the arterial tension slightly augmented. Von Vivenot observed the following modifications in the sphygmographic curve: The total elevation is diminished, the up-stroke is more oblique (and less abrupt), the apex

is rounded, and the down-stroke loses its wavy outline, becoming either straight or slightly convex. Liebig obtained very high curves with Marey's sphygmomanometer during the stage of pressure augmentation.

The **capillary circulation** unquestionably undergoes certain modifications. They are especially well pronounced when the pressure attains from three to four atmospheres, and evidence themselves in pallor of the skin and of the mucous membranes. The changes are even more marked in areas of inflammation. Stembo took the peripheral (skin) and central (rectum) **temperatures** and observed a general fall. The peripheral temperature was diminished more than the central.

Effect on the General Nutrition

The changes produced in the general nutrition are not without importance. Experiments in this field demand extreme delicacy; and despite the researches of Pravaz, Liebig, and Paul Bert, our knowledge on the subject is still very incomplete. Paul Bert experimented on himself, on his assistants, and on animals, observing the usual precautions necessary in such cases, which consist in accurate regulation of the food, absolute rest and the like. Nevertheless the various observers have obtained distinctly different results. This is owing partly to the difficulty in maintaining comparable environmental conditions, and partly to the fact that the methods of analysis in this kind of work are extremely complicated. The analysis of the expired air shows a distinct **increase** —2.6 per cent.—of **carbon dioxid** (Paul Bert). An analogous **increase** in the production of **urea** is observed. This increase may be quite considerable, and is observed both in man and in the dog. J. Pravaz reached the same conclusion, and believes that the increase reaches its maximum at the beginning of compression and that it is greater when low grades of pressure are used (20 centimeters) than with high pressures (30 to 70 centimeters). The only trustworthy result of these experiments of Pravaz, which are neither sufficiently numerous, nor above suspicion in the matter of accuracy, is the bare fact that the urea is increased in amount. Hadra experimented on himself with an even more scrupulous attention to details. He found that the quantity of urea was augmented after a séance of several hours in condensed air at two atmospheres. Fraenkel in his animal experiments was unable to determine any modifications in the excretion of urea. According to Loewy, no increase of metabolism takes place in condensed air; on the contrary, after a long exposure to higher pressures a diminution in the oxidation processes is observed. Liebig concludes from a long series of experiments that the consumption of oxygen is increased, and that there is a barely perceptible

difference in the quantity of carbon dioxid excreted. But if the maximum and minimum amounts are analyzed as well as the average amount, a tendency to the formation of a greater quantity of carbon dioxid in condensed air is found.* Simonoff observed in patients who took daily sittings an habitual **increase in the appetite** and, if this appetite was satisfied, an **increase in the body-weight.** Von Vivenot observed a **rise in temperature** during the compressed-air bath which he estimates at 0.5° C. (1° F.); but Stembo reached the opposite conclusion, so that the question still remains undecided.

Effects on the Nervous System

Quite important are the effects which condensed air at a moderately low pressure exerts on the cerebral and nervous activities. These effects seem to depend more on the subject than on the surrounding medium; one patient describes a feeling of languor, a desire to sleep (Lange), while another speaks of a state of general excitement, a kind of drunkenness.

General Review

What is the **cause of this diversity** in the effects observed? The increase in pressure brings about a reduction in the volume of the intestinal gases, and this compression affects the superior wall of the abdomen—the diaphragm—as well as the external walls, through the instrumentality of the air entering the thoracic cage under pressure. Two different effects are accordingly produced, collapse of the abdominal wall and depression of the diaphragm, accompanied by a corresponding increase in the vertical diameter of the thoracic cavity. The first explains the increase in the range of the respiratory movements and the diminution in their frequency,† and there is no need of invoking an increase in the absorption of oxygen, although it must be quite considerable. The diminution in the intrathoracic pressure-variations is also explained by the permanent depression of the diaphragm, which necessarily results in reducing the absolute difference between the inspiratory and expiratory positions. The changes in the circulation may be regarded as dependent upon those observed in the respiratory apparatus. The effect of mechanical action on the pulmonary vessels, causing them to collapse, must be discarded

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* The phenomenon of exhalation of carbon dioxid is, according to an experiment which did not last more than a few minutes, not identical with the production of the gas (Henriot and Ch. Sichel).

† Liebig and certain other authorities, adherents of the theory of mechanical action, seek the cause of the slowing of the respiration in an increased resistance to the air in its passage through the bronchi.

at once. Gréhant and Quinquaud have shown that the pulmonary circulation, and in fact the general circulation, ultimately becomes completely arrested when a certain amount of air is forced into the lungs. There is scarcely need to repeat that the conditions in the condensed-air bath are entirely different and that the effect has nothing to do with unilateral pressure.

To disregard theory and adhere to facts, two factors are obviously of prime importance: (1) the changes in the pulmonary circulation dependent upon the increase in the capacity of the thorax; and (2) those resulting from the diminution in the range of variations of intrathoracic pressure. It is needless to repeat the effect of inspiratory and expiratory pressure-variations on the intrathoracic circulation and, secondarily, on the general circulation. Bliden, in experiments performed on rabbits, did not discover any appreciable changes in intrapleural pressure, but he himself remarks that his conclusions cannot be applied to man, as the rabbit's intestine contains very little gas. Also, the changes resulting from the diminution in the frequency of the respiratory movements must be considered. Furthermore, it has been seen that the change in the respiratory movements consists chiefly in prolonged expiration. Now, at each expiration, owing to the exaggerated inhibition of the heart, the action of the latter is slowed, hence the influence of the respiratory center on the cardiac and vasomotor centers must also be taken into account to a certain extent. The general pallor of the skin and mucous membranes appears to be largely due to this mechanism, and possibly also to certain modifications of the gaseous interchange which have not been satisfactorily determined, probably a greater absorption of oxygen and an increased production of carbon dioxid.* But this is not all. Even if the law of the transmission of pressure be accepted in all its rigor, one must also bear in mind that the thoracic cavity contains an autonomous center of energy to which the inflexible law of the transmission of forces cannot be strictly applied; however, too much importance need not be attached to this point. The cardiac muscle rapidly adapts itself—provided the changes be not too abrupt or too profound—to the new conditions.

To conclude this dissertation, which could easily have been extended to an even greater length, let it be stated that I cannot agree with Simonoff that an exposure to condensed air, during the stage of condensation, can be compared with a series of inspirations from and expirations into condensed air; for, during this stage, pressure acts both on the exterior of the body and on the surface of the lungs. This is one of the

* This fact is supported by the investigations of Stembo, Bliden, and Jacobson.

reasons why I consider it less essential to differentiate absolutely between the stage of increasing compression and the stage of permanent compression. This distinction was formulated by the adherents of the theory of mechanical action, who established it *à priori* and dogmatically, for the sole purpose of supporting their arguments. Everything that has an end must have a beginning and intermediary stages. No matter how rapid the succession of events, the effect of pressure is not instantaneous but progressive; it affects first the surface and later the deeper tissues.

The difficulty of arriving at a definite **conclusion in regard to the physiologic action of compressed air** is obvious from the foregoing discussion. Experiments in this field require a singular delicacy of technic, and it is impossible to regard as constant and definite the results obtained sometimes on a healthy man, sometimes on a sick man; sometimes on a narcotized animal, sometimes without anesthesia; sometimes on an animal of one species, and sometimes on one belonging to another. Just as in a great number of other therapeutic procedures, the wisest plan is to weigh and utilize every fact observed and not to attempt too precise an explanation of the physiologic questions involved.

CHAPTER IV

ABSOLUTE PRESSURE METHOD—THE PNEUMATIC CHAMBER

The Pneumatic Chamber. General Description. Aërotherapeutic Installation at the Jewish Hospital in Berlin. Tabarié's, Lange's, Dupont's, Liebig's, S. A. Fontaine's, Hovent's, and Simonoff's Pneumatic Chambers. Houssaye's Portable Pneumatic Chamber. Management of the Pneumatic Chamber. Therapeutic Uses of the Condensed-air Bath.—Diseases of the Upper Air-passages; Affections of the Bronchi; Emphysema; Asthma; Pulmonary Tuberculosis; Pleural Effusion; Diseases of the Heart; Anemia and Chlorosis; Diseases of the Ear; Other Affections.—Counterindications.

THE PNEUMATIC CHAMBER

Condensed-air baths for therapeutic purposes are taken in pneumatic chambers specially devised for the purpose. The various models differ only in certain details, more or less important as regards convenience and mechanical efficiency, but of only secondary significance when the therapeutic application of compressed air is considered broadly.

Pneumatic chambers vary greatly as to **shape** and **dimensions**; they may represent a cube, a spheroid, or a cylinder; but in every case they are constructed on the same principle—that employed in the construction of Henshaw's chamber or 'domicilium,' and which likewise underlies Smeaton's **diving-bell** and its successors. Sheet-iron of from 6 to 12 millimeters (¼ to ½ inch) in thickness is generally used in the construction of pneumatic chambers instead of stone as used by Henshaw, but masonry has been employed in so modern a structure as Simonoff's. Cast-iron has been abandoned since the accident that occurred in 1896 in the shaft at Douchy, and which was attributed by Comte to a slow decomposition of the cast metal by its constant exposure to considerable pressures and to variations of temperature. The chambers are provided with doors strengthened by numerous rivets and closing with a spring latch; and are pierced by a number of port-holes covered with heavy glass. (See Fig. 12.) The chambers also contain a **lock** or **antechamber** to enable the physician or an attendant to enter and leave the apparatus, if necessary, without disturbing the pressure. The lock, in

addition, makes it possible to supply the patient's wants, such as books, newspapers, drinks, and the like, without interrupting his treatment. In some models one of the windows is made in two compartments for this purpose—an important convenience. The **capacity** of a pneumatic chamber intended for one person should be about 8 cubic meters (approximately 280 cubic feet), and the dimensions must be increased proportionately if the chamber is to be used by several persons at a time. The **shape** is usually cylindrical; the top and bottom of the cylinder being formed by two hemispheric plates, the outer surfaces of which are slightly convex. The windows are immovable and closed by a plate of heavy glass, so that the patient in the chamber can be watched from without. The door opens inward. The chamber is provided with **two pipes,** one of which supplies the air, while the other serves for ventilation; by means of the first pipe the cabinet is connected with a hydraulic compressor operated by steam or electricity. One of the most practical systems is that designed by Fontaine, which is modeled after the hydraulic presses in the mines of Chemnitz.

Among **recent improvements** the following deserve special mention:

1. **Filtration of the air** by passing it through a layer of cotton before its entrance into the chamber (see page 94).

2. The system of **heating or cooling the air** by passing it through a kind of worm, containing a reservoir which may be either heated by means of a continuous flow of hot water, or cooled by means of ice (see page 95).

3. The compressed air, instead of entering at the bottom of the chamber through a single opening, is introduced into a pipe surrounding the entire lower portion of the chamber, and allowed to escape through a number of small openings in the curved portion of the pipe (see page 95).

4. The ventilating tube which leaves the upper portion of the cabinet communicates with an apparatus for **regulating the pressure automatically** (see page 95).

5. An effort has been made to **increase the proportion of aqueous vapor** in the air by passing it through a vessel of water, to which, if desired, certain medicinal substances may be added.

These improvements are found in all the modern pneumatic chambers, and especially in the one used at the Pneumatic Institute of the Jewish Hospital in Berlin, which has been described in detail by Lazarus.

In Paris the compressed air furnished by Popp's factory is used. It is introduced into the lower portion of the chamber, the ventilating pipe being inserted in the upper portion. During a séance of two hours the air consumption for a single person amounts to 8000 cubic meters (10,320

cubic yards or 278,640 cubic feet), so that abundant ventilation is necessary. The **pressure** is kept under constant control by means of a manometer, which can be seen both from within and from without, while the variations in the **temperature** are indicated by a thermometer. Comparatively low pressures are generally used, as the effect obtained is quite as marked and the inconvenience is considerably less. An excess pressure of 30 centimeters (12 inches) of mercury, corresponding to $\frac{2}{5}$ of

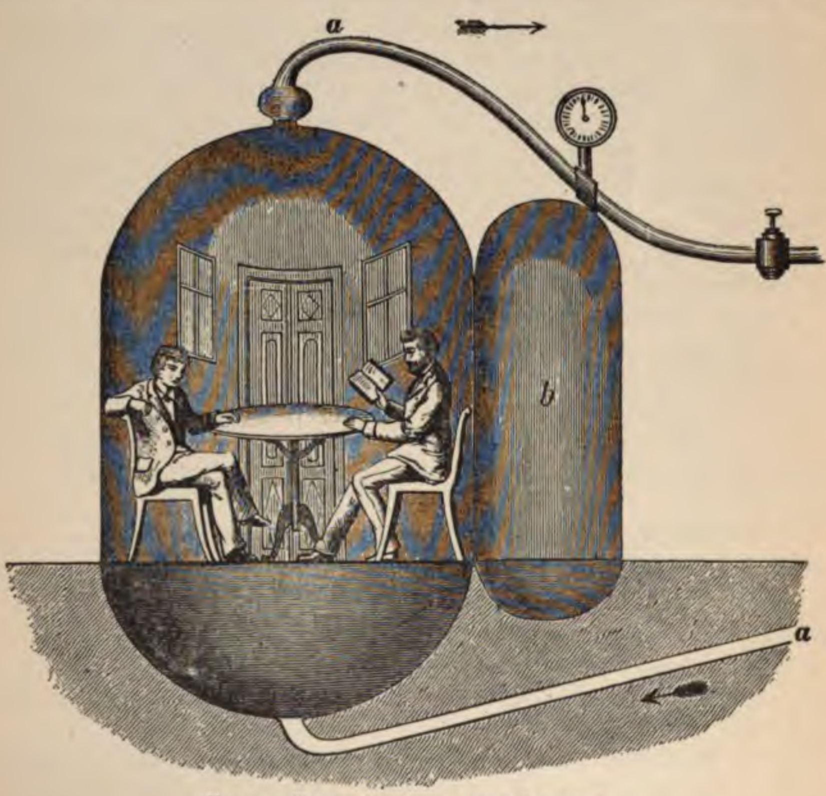


FIG. 9.—TABARIÉ'S PNEUMATIC CHAMBER
a, Afflux tube. *a′*, Efflux tube. *b*, Lock.

an atmosphere, is rarely exceeded. In Germany $+ \frac{3}{7}$ of an atmosphere is the pressure recommended. In the case of a debilitated patient not more than $+ \frac{1}{5}$ of an atmosphere, or 15 to 16 centimeters (6 to $6\frac{1}{2}$ inches) f mercury, is usually employed. In general it may be said that per-sible therapeutic pressures range from an excess of $\frac{1}{5}$ atmosphere to excess of 1 atmosphere.

Tabarié's pneumatic chamber, the earliest of the modern apparatus, is constructed of wrought-iron and spheroidal in shape with the long diameter in the vertical direction (Fig. 9). It is large enough to accommodate a dozen persons; the floor is covered with a carpet which conceals the openings through which the air is forced in by a steam-pump and the walls are upholstered in leather or silk. The air is constantly removed by a ventilating pipe, the rate of efflux being made sufficiently less than the rate of afflux to secure any desired elevation of pressure within the chamber.

Lange's pneumatic chamber differs in shape, and in certain devices for ventilation and the regulation of the temperature, from Tabarié's appa-

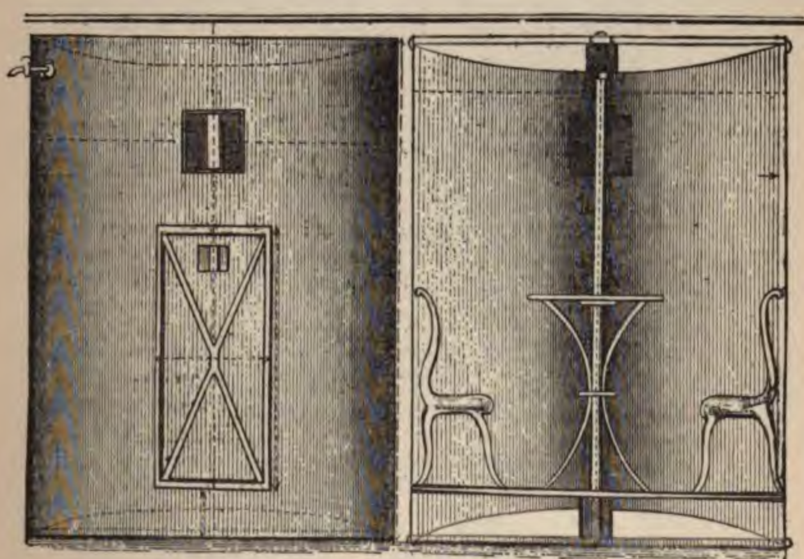


FIG. 10.—LANGE'S PNEUMATIC CHAMBER.

ratus (Figs. 10 and 11). It is cylindrical, constructed of wrought-iron, and accommodates only four persons. The temperature of the compressed air within the chamber is lowered either by means of a stream of cold water directed against the force-pump and the supply-pipes, or by filling the cup-shaped space at the top of the chamber with cold water and allowing it to flow down along the sides, where it is taken up by sheets of linen and cools the air by evaporation. In winter the chamber is kept at a comfortable temperature by heating in the ordinary way the room where it is set up. The chamber is also provided with a device for regulating the flow of the incoming air so that it enters in a steady stream

instead of in a succession of puffs corresponding with the strokes of the force-pump. The pressure is secured, as in Tabarié's system, by regulating the inflow and outflow of the air.

In the Établissement Aérothérapique of Dr. Dupont in Paris the pneumatic chambers are large enough to hold two or three patients; they are lighted during the day by four port-holes of glass and in the evening by electricity, and have a telephone connection with the ex-

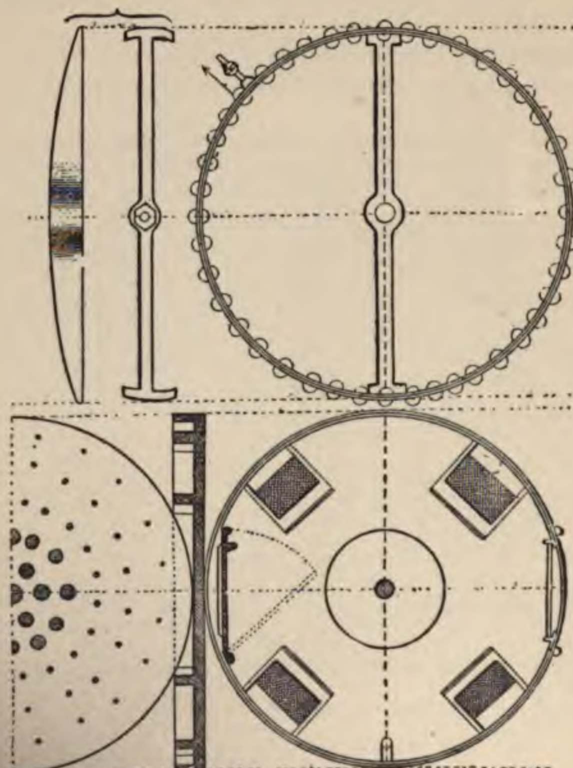


FIG. 11.—LANGE'S PNEUMATIC CHAMBER (CROSS-SECTIONS).

e accompanying illustration (Fig. 12) gives a general view of hment.

13 and 14 represent the engine-room and pneumatic cham-ively of the **Aërotherapeutic Installation at the Jewish Hos-** e air is first pumped through a large pipe into the

'herapie und der therapeutischen Methodik,'' Eulenburg and 98.

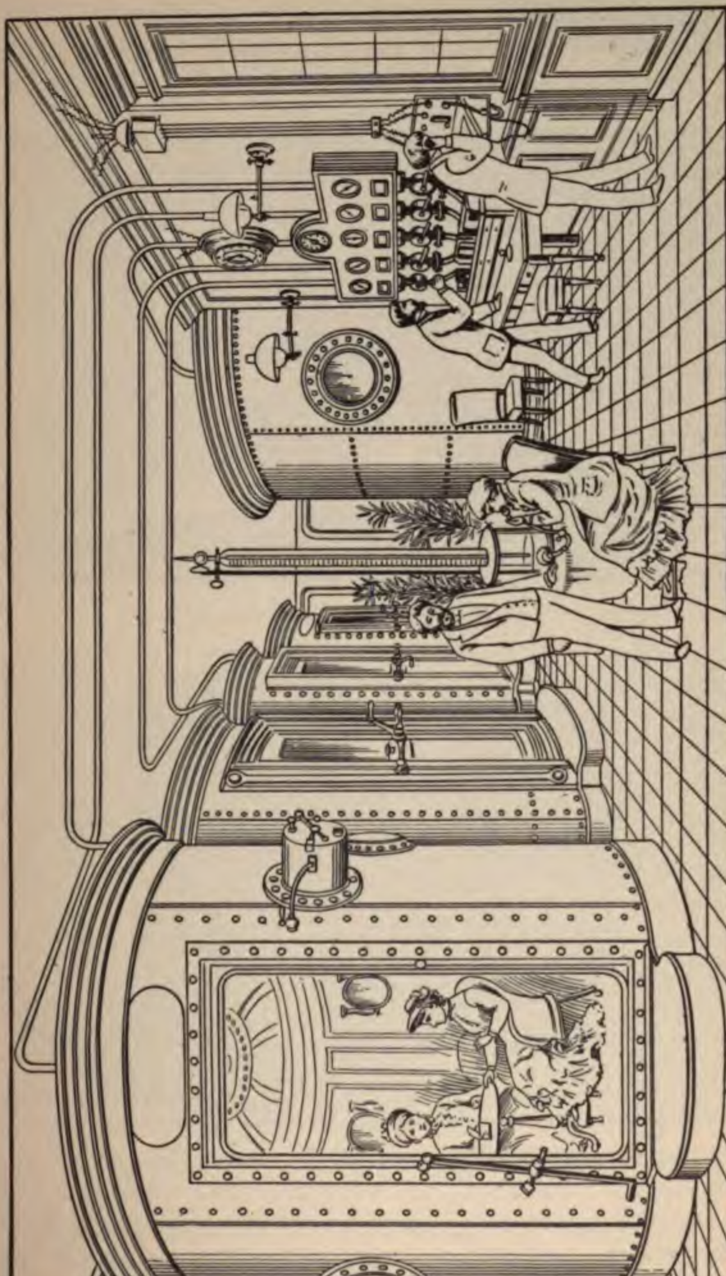


FIG. 12.—PNEUMATIC CHAMBERS AT THE ÉTABLISSEMENT AÉROTHÉRAPEUTIQUE, PARIS.

filter A (Fig. 13). This filter contains several layers of cotton, loosely interposed between wire frames, the object being to arrest the dust, bacteria, and other morphologic elements contained in the air. From

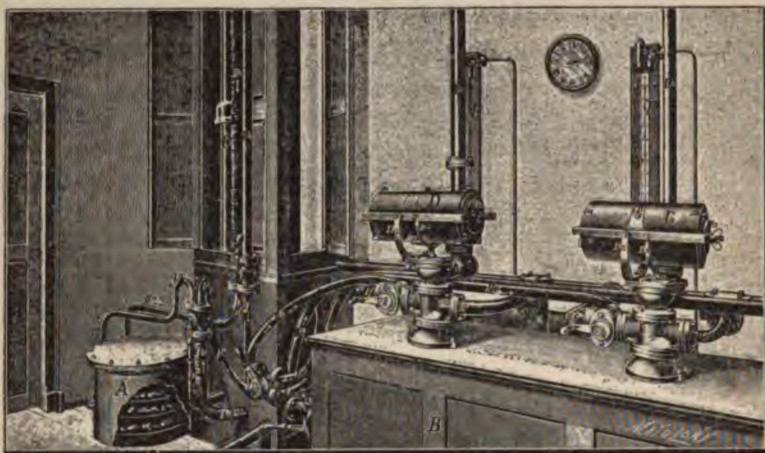


FIG. 13.—ENGINE-ROOM, JEWISH HOSPITAL, BERLIN.

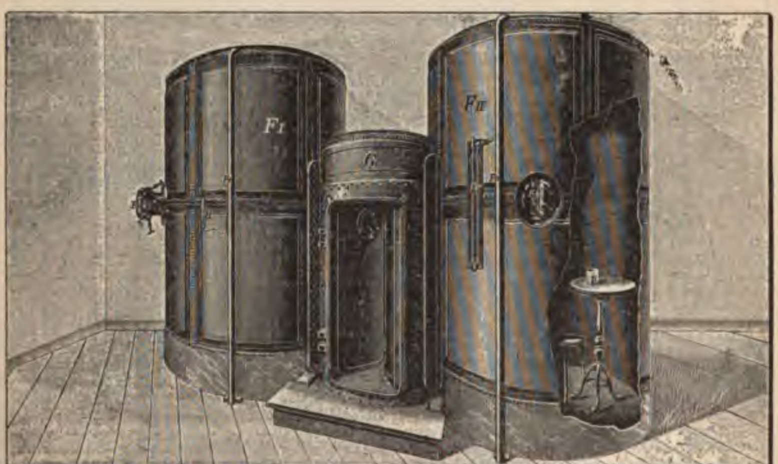


FIG. 14.—PNEUMATIC CHAMBERS, JEWISH HOSPITAL, BERLIN.

the filter the air passes through the pipe Ia to the **three-way stopcock I.** ... he latter is open, the air passes on through the pipe Ia, which ... arge pipe C, filled with hot steam and incased in a wooden box,

as shown in the figure. The pipe Ia enters the lower portion of the **steam-pipe C,** passes through it in the form of a spiral, and emerges again in the lower portion as the pipe Ib, filled with heated air. The pipes containing heated air are wrapped with cloth. The air then passes through the pipe Ic to another **three-way stopcock,** also marked I, and when the latter is closed, through the pipe Ie. If the air is to be cooled instead of warmed, the stopcock between the pipes Ia and Ib is closed, so that the air does not pass through the pipe C; instead, the stopcock between the pipes Ic and Id is opened, and the air is conveyed through the pipe Id into the **space B,** which contains ice. It follows, therefore, that the air in the pipe Ie is either warm or cold, according as the stopcocks between the pipes Ia and Ib, and between the pipes Ic and Id, are open or closed. The pipe Ie ends in a stopcock through which the air is allowed to enter the **pneumatic chamber FI** (Fig. 14). To moderate the pressure, the supply-pipe, which enters through an opening in the side of the chamber, is bent over at right angles and passes horizontally around the floor of the chamber. This portion of the pipe is pierced by numerous openings, so that the air escapes into the chamber quite imperceptibly. From the pneumatic chamber the air escapes through the pipe Fe, which pierces the ceiling, and is conveyed through the pipe Ig back into the engine-room (Fig. 13), underneath the horizontal cylinder D, which is an apparatus for **automatically regulating the pressure.**

The extremities of the transverse axis of this cylinder rest on a frame which is balanced on the support D3. By means of a thumb-screw, D2, to which a pointer and a graduated disk are attached, the cylinder can be rotated about its long axis and adjusted accurately at any desired angle. The **valve, DI,** which is also accurately graduated, can thus be displaced upward or downward. This valve allows the water contained in one-half of the cylinder to flow into the other half. The quantity of water which is to be allowed to flow from one-half of the cylinder into the other half is determined by the position of the valve, which pierces the partition and occupies a deeper position below the level of the water as the cylinder is rotated. The rate of flow is regulated by the size of the opening in the valve, which, as we have seen, is accurately graduated. As soon as the water begins to flow, one-half of the cylinder gradually descends. In doing so it depresses the second support, D4, to which is attached a rod with a circular disk extending into the **pipe Ig.** The lumen of the latter is thus gradually and imperceptibly diminished, *i. e.*, the escape of the air (from the pneumatic chamber) is impeded, and the air in the chamber is therefore compressed. The remainder of the air escapes through the pipe, Ih, which passes through the ceiling of the

engine-room. By this arrangement all danger of stagnation of air in the pneumatic chamber is avoided. In addition to the automatic regulating apparatus, the stopcock situated behind the pipe Ie is used to regulate the quantity of air that enters the chamber.

Suitable provision is also made to regulate the temperature, the degree of pressure to be attained, the time to be occupied by the transition from normal pressure to the desired excess, and the humidity of the air.

Each pneumatic chamber contains three circular windows in the sides and one in the ceiling, each about 30 centimeters (12 inches) in diameter. Through the window Fb the reading on an **August psychrometer** within the air-chamber can be taken. The window Fa acts as a **lock** through which medicines and other small objects can be handed to the patient. Fd is a **manometer** which registers the air-pressure in the air-chamber. A similar manometer is attached to the pipe Ig for the purposes of control. H is a **thermometer** for determining the temperature outside the chamber. The two chambers FI and FII are connected by the **intermediary chamber G,** to be used as a **lock** by the physician.

The dimensions of the apparatus are as follow:

Diameter of Air-chamber (F), ...	1.88 meters (6 feet 2 inches)
Diameter of Filter A, ...	0.60 meter (2 feet)
Diameter of Regulating Apparatus D, ...	0.21 meter (8 inches)
Height of Air-chamber (F), ...	3.40 meters (11 feet)
Height of Filter A, ...	1.60 meters (5 feet 3 inches)
Height of Regulating Apparatus D, ...	0.39 meter (15 inches)

Liebig's pneumatic chamber, which is used at the Dianabad in Reichenhall, is built on a 'trefoil' plan. It consists of three chambers of equal size (each large enough for three persons), and one antechamber, which communicates with each of the three and in which the changes of pressure are produced (Fig. 15). Thus the antechamber acts as a large pressure regulator and protects the inmates from the inconvenience of sudden changes of pressure as the air enters the apparatus. The air escapes through an opening near the ceiling, and the elevation of pressure is produced by increasing the inflow, not by obstructing the outflow, thus maintaining perfect ventilation. One of the two pipes through which the apparatus is supplied with air passes through a box which can be filled with steam from the engine; the other pipe is cooled, if necessary, by passing it through cold water. The temperature is thus readily controlled. By a special arrangement of stopcocks it is made possible to obtain a lower pressure in one of the three chambers than in the other two. Von Liebig gives the maximum percentage of carbon dioxid

that may be allowed to accumulate as 0.15, and describes the method of keeping the air in the chambers up to the standard of purity by determining the percentage of carbon dioxid after Pettenkofer's method. An individual exhales in one hour 300 liters of air, containing 12 liters of carbon dioxid, or 4 per cent. In order to reduce the carbon dioxid to 0.1 per cent., 2000 liters of air must be added for every liter of carbon dioxid, the proportion of carbon dioxid in standard air being assumed to be 0.05 per cent. One person therefore requires 24,000 liters of air in an

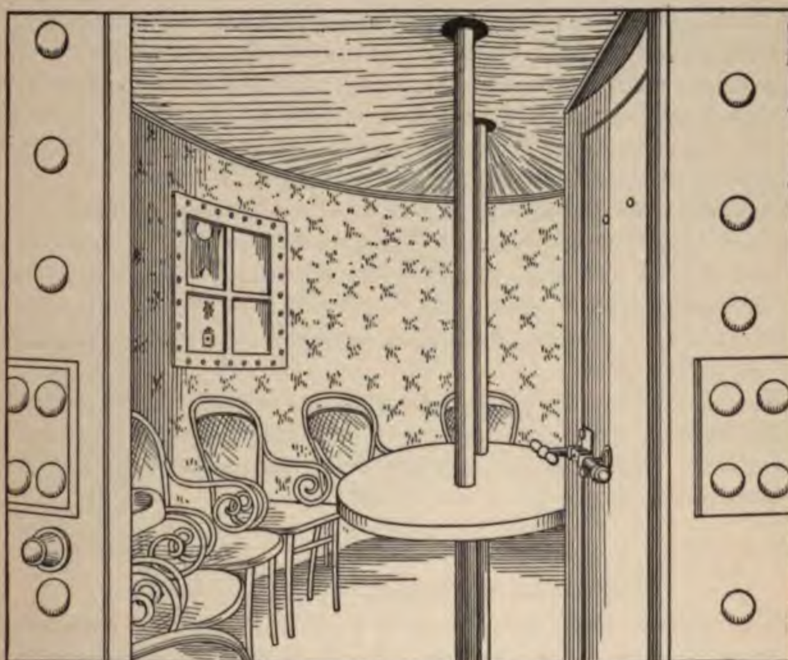


FIG. 15.—LIEBIG'S PNEUMATIC CHAMBER.

hour, and, as the pneumatic chamber holds ten persons, 240,000 liters or 240 cubic meters—say 3500 cubic feet—of air are required every hour.

Brussels Pneumatic Chamber.—At the pneumotherapeutic institution of Brussels there are several iron chambers of different sizes, so constructed that the occupants are always under observation through glass windows, and having a number of ingenious appliances by means of which access to the patient may be had, communication may be held, and articles passed in and out, without much disturbance of the pressure. One or more patients having entered the chamber, wherein are electric

bell, electric lamps, comfortable chairs, tables, reading and writing materials, toys for children, and the like, the contained air is gradually rarefied or condensed by means of a pump worked by a gas-engine. The air passes from the chamber through a series of immense iron wash-bottles containing alkaline solutions, etc., to remove the carbon dioxid and other products of respiration; and returns purified. There is thus a continuous circuit of air under uniform pressure. Special appliances permit regulation of pressure, humidity, temperature, etc. There are attachments for the use of oxygen, nitrous oxid, or other gases, and of medicinal sprays and vapors, when required. After a sitting of from half an hour to two hours the pressure is gradually restored to the normal, and the patient is allowed to emerge. Hovent, as a rule, takes half an hour to reach the maximum pressure employed, maintains it for half an hour, and consumes a third half-hour in the restoration to the norm. All dangers from sudden change are thus avoided.

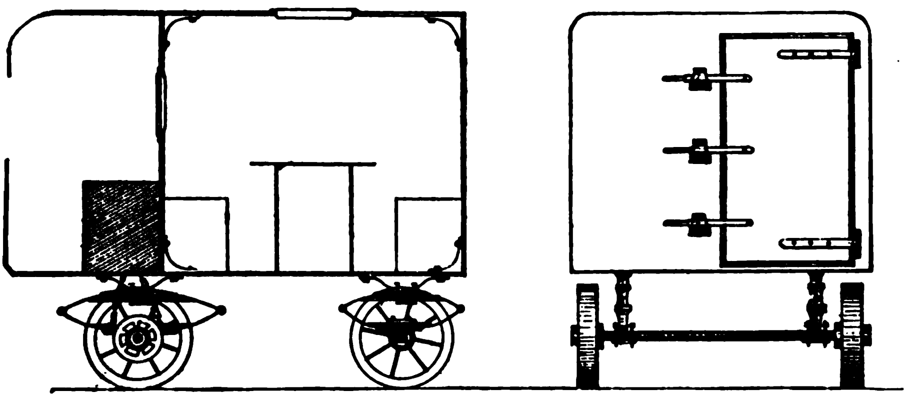
Simonoff, of St. Petersburg, has devised a somewhat different model from that most commonly used. The apparatus consists of two chambers, one of iron, the other of stone; the advantage of the latter being that the temperature is more easily regulated. In this chamber provision is made for a protracted stay, the patients sometimes remaining in it for days at a time.

The essential feature of **S. A. Fontaine's pneumatic chamber** is that the compression of the air is effected by natural water-pressure instead of by steam. The system, while effective, has the drawback of being very expensive.

PORTABLE PNEUMATIC CHAMBERS

Houssaye conceived the idea of a **portable pneumatic chamber,** as stationary ones are to be found only in the large cities. His system, if adopted, would bring the treatment into much more general use. The apparatus, which is mounted on an automobile, is composed of two portions, a force-pump operated by a motor, and the pneumatic chamber with its accessories. The pneumatic chamber is a rectangular prism with rounded corners, having its long diameter in the anteroposterior direction. The length is 2 meters (6 feet 7 inches), and the other dimensions 1.75 meters (5 feet 9 inches) each, making a total volume of 6 cubic meters (about 209 cubic feet). The furniture is made of iron and as simple as possible. An **intermediary chamber** or **lock,** dividing off the posterior third of the cabinet, is optional. The chamber communicates with the exterior by means of a metallic door of the same

thickness as the walls, say, 8 millimeters (about $\frac{1}{3}$ of an inch), fitting into a groove which is lined with hollow rubber tubing filled with air or water to insure hermetic closure. The door is provided with tight-fitting handles and secured by three cross-bars fastened with burrs. If necessary, a port-hole, firmly riveted and large enough to light the chamber, may be added in the ceiling, and a smaller one in the anterior wall. There are **two stopcocks,** one situated below, which allows the air coming from the force-pump to enter, while another, of the same size placed higher up, allows the vitiated air to escape. The furniture should be limited to a table and benches of the same material as the walls, so that the entire chamber and its contents may be disinfected frequently. A mercury **manometer** and **hygrometer,** and two **thermometers,** one inside and one outside, complete the apparatus. Receptacles



Longitudinal Section. Posterior View.

FIG. 16.—HOUSSAYE'S PORTABLE PNEUMATIC CHAMBER.

containing sodium bicarbonate solution to dispose of the carbon dioxid, and calcium chlorid to absorb the aqueous vapor, are placed in one corner of the chamber. Condensation may be effected in two hours. The two thermometers can be attached to the anterior port-hole so as to be compared readily and often. The **temperature** of the interior will vary according to the season; in winter the pipe connecting the pump with the chamber may be surrounded by hot water, and in summer the walls of the chamber may be cooled with a jet of cold water. A chamber of the dimensions stated is capable of holding several persons.

Technic.—The force-pump is placed on the body of the automobile. When the place of destination is reached, the piston is disconnected from the two driving-wheels of the automobile and attached to a jointed

shaft which works the pump. As automobiles have not yet come into general use, this system has never been thoroughly tested; but it is probably the most convenient method proposed for administering condensed-air baths (Fig. 16).

MANAGEMENT OF THE PNEUMATIC CHAMBER

The **duration of a sitting** in the pneumatic chamber is necessarily variable. To avoid unpleasant effects, such as earache, that take place during condensation, and the accidents that occur during decompression, it is well to proceed cautiously at first. When patients have become accustomed to the treatment, the sitting may last on the average for two hours. In France the time occupied in raising the pressure to the desired point is about thirty minutes, while in Germany it is about twenty minutes. There appears to be no good reason for unduly prolonging the first stage, since the unpleasant phenomena that occur are usually evanescent and trifling in character. If it were to be demonstrated that no increase in the depth of the respiratory movements takes place during this stage, it would be a reason for prolonging the time occupied in raising the pressure (Aron). When the desired pressure has been attained, thirty to sixty minutes are allowed to elapse before the pressure is slowly brought back to the barometric figure. The last stage, the period of decompression, should occupy from thirty to forty minutes, and cannot be shortened without risk of grave accidents. In France M. Dupont begins the first sitting with a minimum **excess pressure** of 8 centimeters (3 inches), and a duration of thirty minutes; he then increases the pressure every other day by from 2 to 4 centimeters ($\frac{3}{4}$ to $1\frac{1}{2}$ inches), until a pressure of $+30$ to 35 centimeters (12 to $13\frac{3}{4}$ inches) of mercury has been attained. **Daily sittings** should be given until near the end of the course of treatment, when they may be reduced to one **every other day,** and later to one **every three days.**

The **duration of a course of treatment** naturally varies in different cases; as a rule, at least twenty sittings are required to obtain permanent results. After about twenty sittings certain **signs of intolerance** sometimes make their appearance, and must at once be recognized, as they are an indication for interrupting the treatment. The principal symptom of intolerance is exaggeration of the appetite, coincident with a progressive diminution of the body-weight.

According to von Liebig, the duration of the three stages should be, thirty minutes for the first stage, during which the pressure is raised to from $+30$ to $+35$ centimeters (12 to $13\frac{3}{4}$ inches) of mercury; fifty minutes

for the stage of constant pressure; and forty minutes for the third stage, or stage of decompression. The figures given by Lazarus are somewhat different, twenty minutes for the first stage, sixty minutes for the second, and forty minutes for the third. The editor * advises that the transition from ordinary pressure to the excess pressure occupy thirty minutes; the period of constant pressure one hour, or in exceptional cases two hours; and that at least thirty minutes be taken to bring the pressure back to normal.

THERAPEUTIC USES OF IMMERSION IN CONDENSED AIR

It is not easy to draw up a logical scheme of **indications** for condensed-air baths, for this form of pneumotherapy has been largely under the influence of an erroneous, theoretic conception—the direct compressing action on the pulmonary blood-vessels. There was a time when condensed-air baths were employed much more frequently and in a greater variety of conditions than they are at present; and although it is impossible to establish *à priori* the indications for the procedure, it would seem to be possible at least to utilize as a guide the facts observed and the therapeutic results obtained. The slight extent of the direct changes produced by these air-baths in the respiration, circulation, and nutrition, and our want of precise knowledge not only as to the degree, but also as to the exact nature of these changes, combine, as will be readily understood, to foil every attempt to base the practical applications of the method on a knowledge of its physiologic effects. On the other hand, in analyzing the clinical observations, which are quite numerous, although not very convincing, individual nervous reactions and the element of suggestion must be taken into account. These two factors are never absent, and play an important part in every new therapeutic method. In the case of the condensed-air bath everything combines to exaggerate the effect of the novelty:—the mere fact that the patient spends some time in a cabinet that is found only in certain institutions; the complicated nature of its construction and the formalities attending its use; the length of the sittings; the minute care displayed in producing the condensation and bringing about the return to standard pressure; the multitude of precautions taken to avoid accidents; and, finally, the sudden and—at least so far as the patient is concerned—the unexpected appearance of certain subjective phenomena such as earache and the like.

* "Air, Condensed or Rarefied," Foster's "Practical Therapeutics," vol. 1, N. Y., 1896.

In what follows no attempt will be made to exhaust all the possibilities of the condensed-air bath, and only those conditions in which its efficacy appears to be well established by trustworthy clinical observation will be noted. In each practical instance the mode of action of the bath will receive due consideration, but cases in which the results must be attributed solely to suggestion, as in various nervous disorders, will be omitted.

DISEASES OF THE UPPER AIR-PASSAGES

The effect of condensed-air baths on the mucous membrane of the **nose, larynx, and trachea** is easily understood when it is remembered that one of the first effects of exposure to condensed air is the diminution in the flow of blood to the upper air-passages. It has already been stated that this decongestive effect can be explained without invoking the mechanical action of pressure; and, whatever may be the correct theory, the undeniable, brutal fact remains and has been noted by all observers. Following the advice of Arago, Francoeur, his colleague at the Académie de Science, employed the condensed-air treatment at Tabarié's institution in a case of **laryngitis with aphonia.** Since then a number of observations have been reported, and Sandahl, of Stockholm, reports recoveries in 80 per cent. of his cases. It is related that Gambetta, when his voice had been exhausted by the oratoric contests in the assembly, renewed his vocal strength in the pneumatic chamber.

Acute attacks of **hoarseness, laryngeal, tracheal, and bronchial catarrh,** are often rapidly relieved by the compressed-air bath.

AFFECTIONS OF THE BRONCHI

The changes in the pulmonary circulation that accompany exposure in the pneumatic chamber readily explain the good effects that are obtained in all affections of the bronchi characterized by hyperemic tumefaction of the mucous membrane, such as **dry catarrh, partial passive congestion** (Labadie-Lagrave), and certain **subacute inflammations.**

Whenever certain regions of the lung are nearly or quite impermeable to air, exposure to condensed air is followed by the most satisfactory results. Such conditions are found in **atelectasis**; **sclerosis** following repeated attacks of **bronchopneumonia**; and sclerosis of **pleural, bronchial,** or **pulmonary** origin. The **mode of action** of condensed air in these cases is readily understood. Owing to the increase in the capacity of the thorax, the lungs tend to expand and increase their volume—to unfold, as it were; but this is probably not the only process at work,

and the compensatory increase of the pulmonary ventilation in the healthy portions of the lungs comes in for its share of attention, if, indeed, it does not represent the principal part of the mechanism.

The mode of action in **chronic bronchial catarrh** is more difficult to explain, although the most favorable therapeutic results have been credibly reported in this disease. It is evident that, owing to the narrowing of the tubes, the passage of the air is impeded both in inspiration and in expiration, causing a true chronic dyspnea. As the volume of the lungs is increased, the favorable influence of the heightened pressure in the pneumatic chamber is all the more remarkable. The diaphragm is already depressed and the mean position of the lungs is lower than normal—conditions that are both theoretically enhanced by exposure to high pressure. It is probable, however, that the further descent of the diaphragm is prevented by the resistance of the compressed intestinal gases and by the increased negative pressure in the pleura; while, on the other hand, a certain increase in the volume of the lungs is indispensable if the circulation of the air in the constricted bronchi is to be improved, and the dilatation of the tubes incident to this expansion of the lungs is reinforced by the increased density of the air. This mechanical extension of the respiratory area is then followed by a chemical effect, consisting in an increase of the gaseous interchange; dyspnea and cyanosis disappear as more oxygen is absorbed; and, in short, the respiratory sedative effect of the condensed-air bath observed in normal individuals is even more pronounced in persons suffering from the dyspnea of chronic bronchial catarrh.

EMPHYSEMA

It is in emphysema that the compressed-air treatment has been most frequently employed and has given the best results. The dyspnea diminishes rapidly; the attacks of oppression subside; and when there are phenomena of passive congestion, with dilatation of the right heart, the respiratory murmur is often observed to reappear at the bases; râles disappear; and the volume of the heart diminishes. According to Dujardin-Beaumetz, the compressed-air bath is one of the few effective therapeutic procedures. Leyden also breaks a lance in favor of the method, although Devois states that he never had any success with it.

For those who believe in the mechanical action of compressed air the **mode of action** is quite simple—the compressed air directly relieves the congestion in the affected tissues. But for us, who do not accept this theory, it is rather more difficult to understand how a method of treat-

ment, the probable effect of which is to increase the size of the thorax, can exert a favorable influence in cases in which the volume of the lung is already increased and the diaphragm is depressed. Several factors no doubt enter into the problem: (1) The improvement in the pulmonary ventilation resulting from the increase in the capacity of the thorax, which, however, is still below the normal. (2) The more rapid interchange of gases, consisting in a greater absorption of oxygen and more active elimination of carbon dioxid. Now, it is well known that the gaseous interchange is materially diminished in emphysema, and, as the hemoglobin of the blood does not undergo any material qualitative or quantitative change, there seems to be no doubt that an increase in the amount of oxygen supplied must be followed by increased absorption. (3) The general sedative effect of condensed-air baths. Lazarus is extremely guarded in his expression of opinion in regard to the value of the condensed-air bath in emphysema, and refuses to admit patients with rigid thorax and arterial sclerosis into his apparatus. He believes that the cabinet is indicated in catarrhal conditions of the bronchial mucous membrane, and that the good results obtained are inversely proportional to the degree of pulmonary distention that has already developed. Increased pressure within the bronchi facilitates their expansion and acts as a stimulus to the torpid character of the chronic catarrh. The distention of the pulmonary tissue cannot, of course, be influenced. In a pronounced case of emphysema the condensed-air treatment is of no value; it is more likely to be useful in cardiac forms accompanied by passive hyperemia of the bronchial walls. Hoffmann, while not very enthusiastic himself, takes exception to the extreme conservatism of Lazarus, and asserts his belief that persons suffering from emphysema often experience great relief in places like Reichenhall, where there is a popular pneumotherapeutic institution.

ASTHMA

In true spasmodic asthma the results obtained are not very convincing and, if genuine, must be attributed chiefly to a sedative action. Sandahl reports recovery or improvement in 75.3 per cent. of his cases, and Bertin in 95 per cent. Hovent is equally enthusiastic.

In asthma occurring as the result of **catarrh** the effects of the treatment are said to be marked. It is to be observed, however, that condensed air cannot be employed during the height of an asthmatic attack on account of the extreme bronchial spasm which the increased air-pressure is unable to overcome. The patients under these circum-

stances find a sitting in the pneumatic chamber distressing, and rapidly become tired. But immediately after the crisis of the attack has been passed the effect of condensed air is remarkable. Within an astonishingly short time an attack of asthma that had kept the patient up the entire night is completely relieved in the pneumatic chamber.

PULMONARY TUBERCULOSIS

The condensed-air bath is theoretically indicated in the same class of cases as are benefited by residence at altitudes. There is testimony from trustworthy observers to the effect that it is of signal advantage in the prevention of extensive lesions in predisposed subjects with early manifestations of tuberculous infiltration; that it relieves chronic congestive and inflammatory conditions of the air-passages, and attacks of acute and subacute bronchitis, which might lead to pulmonary catarrh and eventually to phthisis; that it promotes the absorption of pleuritic effusions; and that it exerts a beneficial influence over general and pulmonary nutrition even in advanced cases. Duvay, of Lyons, reports good results, but the number of his observations—five—is too small to have much value. Oertel knows of no therapeutic procedure comparable to the condensed-air bath in combating the tuberculous process, providing the method is employed in time and persevered in. Fontaine, Dupont, and Houssaye have also expressed this encouraging belief, but it would be premature at the present time dogmatically to recommend the systematic employment of condensed-air baths in preference to altitude, even in cases of torpid tuberculosis in the early stage of the lesions. Before any accurate rules can be formulated for the guidance of practitioners, the question will have to be studied with still greater care and in a much greater number of cases. From this viewpoint, the method is worthy of extended employment. It must, however, be **avoided** in the presence of persistent high temperature, of recurrent hemorrhage, of active softening, or of suppuration.

PLEURAL AFFECTIONS

In **delayed absorption of pleural effusion,** and when the acute phenomena of pleuritis have long disappeared, the condensed-air treatment is followed by rapid improvement, and the results are practically constant. The depression of the diaphragm facilitates the expansion of the lung, increases the circulation in the pulmonary pleura, and accordingly hastens the absorption of the fluid. The fact that absorption is taking place can sometimes be demonstrated after each sitting, by examining the patient

with the fluoroscope, with the pneumatometer and the spirometer, by auscultation, and by percussion. In one of my cases in which, to the patient's great despair, an effusion following a frank attack of pneumonia remained stationary for four weeks although the fever had disappeared and the general condition was excellent, two sittings sufficed to bring about a considerable degree of absorption—more than one-third—a fact which was verified by percussion, auscultation, and radioscopy.

But these are not the only indications for the use of condensed air in patients suffering from pleurisy. There are cases in which a pleural rub persists for months owing to a **thickening of the pleura**; or troublesome **adhesions** remain that interfere with the expansion of the base of the lung; or, finally, the patient may be troubled by more or less severe **pain,** making it impossible for him to draw a deep breath. The result of all this is that the lung is unable to recover its normal power of expansion, a condition the gravity of which does not need to be specially emphasized. In all these cases condensed air gives more rapid and more satisfactory results than can be expected from any other therapeutic procedure. As will be seen later, the full bath of condensed air can in most cases be advantageously substituted by inhalations with a portable apparatus; but in the cases now under consideration inhalations are not to be depended upon; for in the latter method the physician must appeal to the patient's will-power, and as every forced respiration is accompanied by pain, it is difficult, not to say impossible, to induce the patient to continue the aërotherapeutic exercises. In the pneumatic chamber, on the other hand, pulmonary expansion takes place gradually and without the cooperation of the patient.

DISEASES OF THE HEART

The heart may be benefited in various ways by the condensed-air bath. Owing to the increased negative pressure in the pleural space, an abundance of oxygenated blood is supplied to the coronary arteries and the nutrition of the heart is thereby increased; while its working capacity is enhanced by the expansion of the lungs which facilitates the action of the right ventricle.

Patients suffering from **valvular disease without compensation** are sometimes troubled with pulsating arteries and difficult breathing. These symptoms usually subside during the stage of constant pressure, but as soon as the air-pressure begins to return to normal, the troublesome symptoms return with renewed vehemence and the patients feel worse than before. Condensed air is therefore **coun-**

terindicated in such cases. When **palpitation** of the heart depends on **nervous** disturbances, on the other hand, the compressed-air treatment is often very beneficial.

In valvular disease **with compensation** the increased air-pressure is well borne, and patients of this class may be treated for their catarrhal troubles without fear of untoward results. Patients with tricuspid insufficiency have repeatedly returned to Reichenhall after they had been entirely cured of their catarrhal symptoms, because of the relief and increased sense of comfort they experienced in the condensed-air chamber.

Whenever the **heart-muscle** is in good condition, whether there be mitral insufficiency or some other valvular affection, the pneumatic chamber gives excellent results in **pulmonary stasis with dilatation of the right heart.** The signs of congestion, such as dyspnea and cyanosis of the extremities, are made to disappear by the action of the condensed air, which stimulates the pulmonary circulation and increases the gaseous interchange. The treatment is quite frequently followed by a distinct general improvement in the entire organism, the strength of the pulse is increased, and the absorption of edematous fluid hastened.

Also in **moderate dilatation of the heart** without valvular lesion the method is sometimes of great benefit in the relief of respiratory and circulatory embarrassment; but if it fail to give relief, or if the relief experienced during a sitting be followed by increased discomfort, it must be **discontinued.** In **advanced muscular disease,** especially if there be considerable **arteriosclerosis** also, the pneumatic chamber is **dangerous.**

ANEMIA AND CHLOROSIS

The use of condensed air in anemia and chlorosis is based on practical experience rather than on theoretic considerations. The value of the treatment in these conditions owes its origin to the accidental discovery that anemic mothers who entered the condensed-air chamber with their children when the latter were treated for whooping-cough or for some other affection involving the respiratory tract, often experienced a distinct improvement in their general condition at the end of a course of sittings. The good effects are attributed by most observers to the increased oxygenation of the blood, and the consequent improvement in the metabolism, the digestion, and the appetite. This no doubt is also the explanation of much of the benefit of the method in pulmonary tuberculosis and in diabetes. The best results are observed in secondary and in symptomatic forms of anemia.

DISEASES OF THE EAR

The attempt to apply condensed-air treatment to certain affections of the internal ear rests on a logical basis. The first cures reported were accidental and occurred in cases of obstruction of the Eustachian tubes. A few of these have already been referred to in connection with caisson-workers, and there may be added the case of a miner who became deaf at the siege of Antwerp and recovered his hearing while working in the collieries of Chalonnes. Sandahl, of Stockholm, used the method systematically, and reported 62 cases of recovery or distinct improvement. Lange has published 16 cases of complete cure. Hovent is enthusiastic in commendation of pneumotherapy in this connection. Although I have frequently resorted to the method, I have seen no brilliant result. In **sclerotic otitis media** the improvement in the tinnitus aurium was only exceptional and temporary, and the hearing was never improved. In **chronic catarrh of the internal ear,** with or without hemorrhagic effusion, when the tympanic cavity is displaced toward the external auditory meatus, the results are more encouraging, but they are not markedly better than can be obtained by much simpler methods.

Other Uses of the Condensed-air Bath

Encouraging results have been obtained with condensed-air baths in **diabetes** (Fournier), and in **obesity** (Katschenowitz and Charrier). Simonoff observed five cases of moderate obesity in which a diminution of the adipose tissue took place while the absolute body-weight increased. These patients did not begin to lose weight until they had had 30 sittings. Sandahl also states that a large number of sittings are required to effect a diminution in the body-weight. The emaciation in the compressed-air chamber evidently depends on an increase in the quantity of oxygen respired, but the determining factors differ in every case, and it is impossible to foretell the result of the treatment.

Whooping-cough is said by Sandahl to be successfully treated in the condensed-air chamber. Not more than three weeks are usually required to effect a cure, and not infrequently 9 or 10 sittings suffice. The children should of course be treated in a separate chamber on account of the danger of infection.

Hernia.—According to Paul Bert, the condensed-air bath has been employed with advantage for the reduction of hernia. The external pressure becomes greater than the intra-abdominal pressure, so that with a pressure of 106 centimeters, or 30 centimeters higher than normal,—in other words, the condensation usually employed,—the pressure exerted

on the surface of the body is equivalent to from 21,620 to 27,760 kilograms, which exceeds the normal pressure by 6120 to 8140 kilograms.

Condensed air, finally, has been recommended in a variety of conditions, some of which may be mentioned briefly. **Hemorrhage,** especially capillary hemorrhages from the bronchial mucous membrane, and epistaxis may be controlled or prevented by its application. It has been used in **diphtheria, eclampsia, cyanosis** (Gintrée), **hemoglobinuria, deformities of the thorax, Pott's disease** and **coxalgia, scoliosis,** and **scrofulous disorders.** It has been recommended in conditions of **cerebral congestion,** and for the relief of **toothache** when not due to caries of the teeth. As to these uses, I have no experience, and can say nothing further.

COUNTERINDICATIONS TO THE USE OF THE PNEUMATIC CHAMBER

The first point to be considered in the therapeutic use of condensed-air baths is their effect on the **bronchial secretions.** It is acknowledged by all the authorities that a material diminution of these secretions takes place; while some, among whom Lazarus may be mentioned, observed that the diminution of the secretion was accompanied by dyspnea and cyanosis lasting several hours and disappearing only with the return of expectoration. In attempting to explain this diminution most of the authors, unable to rid themselves entirely of the idea of an unopposed pressure, attribute it to inspissation. But in my opinion the explanation is much simpler. Any modification of the secretion poured out by the mucous membrane of the trachea or of the large bronchial tubes must be due to the circulation in these structures. When, however, the finer bronchial ramifications are at fault, the secretions may completely obliterate the lumen of the bronchiole, especially during inspiration, and thus lead to the formation of a small pneumatic pouch which does not communicate with the atmospheric air and is therefore subject to the same conditions as the gases in the intestinal tract. This obliteration of the bronchioles often takes place in chronic conditions, and in rare instances persists for some time, leading to gradual absorption of the air contained in front of the obstacle and to atelectasis of the corresponding pulmonary region. In condensed air, however, the depression of the diaphragm has the effect of increasing the quantity of inspired air and of bringing about more complete and more universal expansion of the alveoli, thus facilitating the occurrence of obstruction in the bron-

chioles. In addition, this obstruction, once produced, is more difficult to remove than it would be under normal conditions in which expiration or, if necessary, the act of coughing usually suffices to remove it; for, owing to the compressibility of the gas confined within the inclosed space, the mucous plug which obliterates the bronchus is in a sense forced into the closed space with a violence directly proportional to the height of the atmospheric pressure during the stage of compression. The pneumatic chamber is therefore **counterindicated** in all forms of **capillary bronchitis.**

The other counterindications are:

1. The existence of lesions which interfere with the descent of the diaphragm and consequently with the expansion of the thorax—such as high grades of **ascites, hydrothorax, abdominal tumors,** and the like.

2. The condition of the **heart.** Certain observations made on caisson-workers lead us to regard a grave affection of the heart as an absolute counterindication; in other words, any **deterioration of the myocardium,** whatever may have been the primary lesion.

3. **Fever.** It has been asserted that the habitual increase of oxidation processes within the body, present in any febrile state, is exaggerated by exposure to condensed air; but too much dependence should not be placed on this theoretic assertion. Nevertheless, clinical observations appear to show that while the existence of slight fever, such as that which accompanies subacute affections of the respiratory passages, is not to be regarded as a counterindication, the case is different when the fever is intense.

4. The existence of **advanced tuberculous lesions,** particularly when there is a **tendency to hemoptysis.** As to these conditions, it is necessary to make certain reservations. In the febrile forms of rapid pulmonary tuberculosis; in the chronic form, during the period of cavity-formation; and in cases characterized by the recurrence of hemoptysis at comparatively short intervals, there cannot be the slightest doubt that the condensed-air treatment must be forbidden absolutely. But is this always the case? The question of hemoptysis is regarded as the pivotal point by certain authors. While some assert that the pneumatic chamber is an excellent preventive or even curative measure in hemoptysis, others go so far as to condemn the employment of condensed air in the case of any patient who has had a single hemorrhage, even when years have elapsed since its occurrence,—fifteen years in a case reported by Lazarus,—and even when the lesions that are present are slight and limited in extent. Nevertheless, there appears to be no doubt that in cases of torpid tuberculosis, and for patients in whom the lesions show

a tendency to undergo sclerotic change and in whom emphysema frequently develops—the phthisis of arthritic patients, according to the older writers—condensed-air baths give excellent results, relieving the dyspnea, rousing the appetite, and improving the general condition.

Hovent does not find absolute counterindications either in fever or in hemorrhagic tendencies, and the editor had the opportunity to examine patients of this observer that had been benefited despite these symptoms. In all probability, the truth is that the same indications hold here as in treatment by altitude; the **personal equation** is to be considered carefully in the case of each individual patient, and theoretic objections must fall before the experience that demonstrates the instability of their theoretic basis.

Diseases of the kidneys, of the **liver,** and of the **intestines,** in which an increased supply of blood would be harmful; certain states of the **brain** and of the **spinal cord**; and **muscular weakness,** have also been regarded as counterindications, but without good reason. For, on examining the writings of the authors who established these counterindications, it is found that they were written under the influence of a fear that I believe to be unfounded—the fear that compression of the peripheral portions would bring on congestion in the deeper organs of the body.

CHAPTER V

EFFECTS AND USES OF RAREFIED AIR

The Rarefied-air Bath—Historical Review. Effects of Rarefied Air. Therapeutic Uses of Rarefied Air. Balloon-Ascensions—General Historical Review. Physiologic Effects of Low Barometric Pressure:—Effect on Blood-Pressure, on the Velocity of the Blood and on the Pulse-rate; Effect on the Respiratory Apparatus; Tension of the Intra-alveolar Oxygen; Effect on the Digestive Apparatus, on Innervation and Locomotion, and on Nutrition; Effect on the Ear. Phenomena Developing during Balloon-Ascensions. Prophylaxis. Mountain-Ascensions—Historical. Symptoms of Mountain-Sickness; Conditions Determining the Onset of Mountain-Sickness; Mountain-Sickness and Fatigue. Conclusion. Adaptation of the Organism to High Altitudes—Respiration; Metabolism; Effect on the Blood—Theories:—1. Concentration of the Blood. 2. Increase in the Vital Resistance of the Erythrocytes. 3. Modification in the Distribution of the Erythrocytes in the Blood. 4. Increased Hematopoiesis. Therapeutic Application.

THE RAREFIED-AIR BATH

To study the effect of a diminution of air-pressure on the living organism, two procedures are available. One, which *à priori* appears to be the most simple and the easiest, consists in transporting the subject of the experiment into higher regions of the atmosphere by climbing mountains or ascending in a balloon. The physiologic data that have thus been obtained are numerous and possess considerable importance; nevertheless, this method, it may as well be stated at once, is the least satisfactory. The reason, or rather the various reasons, for the innumerable contradictions in the results of different experimenters will be discussed in another place. The other procedure consists in placing the subject of the experiment in a bell or cabinet in which, without any draft, the pressure of the air can progressively be diminished. This corresponds with the method that has already been utilized in studying the effects of increased pressure.

Historical Review

The idea of utilizing in medicine a diminution of the atmospheric pressure is coeval with the earliest applications of condensed air.* But for some time previously, even before Torricelli's discovery, which made it possible both to demonstrate and to measure the pressure of the atmosphere, certain investigators had studied the effect of a vacuum on animal life. It would take too long to summarize, as was done in the section dealing with increased pressure, all the observations and all the theories that have been offered in the chronologic order of their appearance. It seems preferable to group them as much as possible under a few leading names, utilizing as a guide the extensive work of Paul Bert, especially for the period preceding its publication.

The earliest investigators for some time confined themselves to the study of the **effect of a vacuum**; *i. e.*, a total abstraction of air (experiments of Van Musschenbroeck, performed in the Academia del Cimento). A rabbit was placed in a glass receptacle, and by means of an air-pump all the air was withdrawn; the animal at first was extremely restless, gasped for air, and then began to swell in every direction: the eyes started from the head, the belly became distended, the animal sought for a means of escape in every part of the receptacle, rose on its hind legs while breathing with the greatest difficulty, then became weaker and weaker, fell to the ground in convulsions, lay on its side, and finally died. These events all occurred within the space of half a minute, after the air-pump, which rapidly withdrew all the air in the vessel, was put in operation. When the air was allowed to re-enter, the animal's body immediately collapsed, and when the chest was opened the lungs were found to be small, flaccid, consolidated, and of a higher specific gravity than water. According to this author, death is due to a stoppage in the circulation of the blood resulting from the collapse of the pulmonary tissue, from which all the air has been withdrawn by the vacuum; in addition, the blood-vessels, especially those of the brain, are obstructed by the gases that are set free from the blood.

R. Boyle, in a work of some importance, shows that new-born animals possess a greater resistance. He states his conclusions as follow: "When it is recalled how the air-pump brings to light quantities of air which before had been invisibly retained in the pores, not only of water, but also of blood, of serum, of urine, of bile, and of the other fluids of the

* Gondret appears to have been the first to think of utilizing rarefied air for therapeutic purposes; he writes: "Perhaps it will some day be possible to construct cabinets in such a way that by means of an air-pump they may be filled either with condensed or rarefied air, according to the exigencies of the case."

human body; when it is considered that the pressure of the atmosphere and the elasticity of the air act upon liquids and on bodies immersed in those liquids, as well as on solid bodies directly exposed to the air, it is probable that **simple alterations in the weight of the atmosphere** may in some cases exert an appreciable influence even on man, both in health and in disease. If, for example, the surrounding atmosphere suddenly becomes lighter than it was before, or than it usually is, the spiritual or aërial particles, numbers of which are retained in the blood, naturally distend that fluid, and may thus dilate the large vessels and bring about an appreciable change in the rapidity of the circulation of the blood in the capillary arteries and veins."

The names of physicists, such as Stairs, Huyghens, Papin, du Hamel, who, unlike Musschenbroeck and Boyle, studied only the action of a perfect vacuum, will be mentioned only to be dismissed. In order to avoid repetition in the discussion of the theories put forward to explain mountain-sickness, the present discussion will be confined to certain theories based on the results of experimental researches.

According to Haller, who took up a suggestion of Cigna,* there is a great difference between air rarefied by abstracting a portion of its volume and air that is lighter because of an increase in altitude, where respiration is more free. Cigna, whose work is in many respects remarkable, has demonstrated: first, that when animals are placed in receivers in which the pressure is diminished, the duration of life is in direct proportion to the size of the receiver; second, that if the air is renewed at frequent intervals, the animals survive. He concludes that rarefied air is not injurious on account of its diminished density, but that it is more rapidly vitiated than air under normal pressure. The asphyxiation of animals confined in closed vessels containing rarefied air is "the work of gases."

The theory that the effect is due to lessening of the **resiliency of the air** (to adopt an expression of the eighteenth century physicists)—*i. e.*, of the pressure that acts mechanically—has found numerous adherents. Under normal pressure every square centimeter of the human body supports a weight of 1.03 kilograms; *i. e.*, the weight supported by the entire body-surface of a man of ordinary size is equivalent to 18,000 kilograms (18 tons). This enormous weight, which ought to crush us, is not felt, say

* When an animal is placed under the receiver of an air-pump, or when a man gradually s to a considerable altitude, both the sudden dilatation of free elastic fluids, which is pronal to the rapid diminution of the atmospheric pressure, and the tendency to dilatation exists in the animal fluids themselves, especially in the elastic fluids which they hold in oduce certain physical effects, such as a general feeling of malaise.

the authors, because it is counterbalanced by the internal tension of the juices of the body; but, so soon as the weight is diminished, the tension of the body-juices, being no longer counterbalanced, forces the fluids toward the periphery, fills the skin with blood, causes it to swell and become congested, and, by rupturing the blood-vessels, brings on hemorrhages; the body, in short, acts as if it were immersed in an enormous cup (Paul Bert). This theory was accepted by Haller, by Hallé and Nysten, by Brachet,* and more recently even von Vivenot defended it.

Giraud-Teulon, Gavarret, and Paul Bert, however, long ago entered a formal protest against this theory as being absolutely contrary to the most elementary physical laws, and in violation of the principle of the incompressibility of liquids. Valentin has calculated that a diminution of pressure of one-half an atmosphere would not affect the volume of the body by more than about $\frac{80}{1000}$. It is evident that any rise or fall in the pressure exerted on the human body under conditions of **complete immersion** in the given atmosphere—which, it is to be observed, affects the lungs as well as the exterior—is immediately counterbalanced and neutralized by becoming diffused over the entire body, since the latter is wholly composed of solids and liquids. Although the pressure on the surface of the skin, and on the outer wall of the blood-vessels, is diminished, there is an absolutely equal diminution internally, and no change in the state of equilibrium is produced (Paul Bert). If the fluids of the body were kept in their place by atmospheric pressure, a very slight diminution of this pressure would evidently suffice to bring about much more grave and terrible disorders than the slight changes observed under such circumstances. As has already been stated, many of the erroneous conceptions are to be attributed to the fact that the effect of complete immersion in rarefied air has been compared to the action of a large Junod cup applied to the entire body—forgetting that in the case of the cup there is only local rarefaction and thus the swelling, the congestion, and the local hemorrhages are produced by the pressure on the rest of the body.

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* A column of air sufficient to cause the barometer to rise only to the height of 13.5 inches must exert on the body and on all the surfaces with which it comes in contact an infinitely smaller pressure, the effect of which may be compared to that of Junod's large cup, and which might, therefore, be regarded as a kind of suction (negative pressure); the capillaries, being less compressed, must therefore react less powerfully on the blood and on the other liquids that course through them; hence they become distended by these fluids and engorged by a sort of stasis. The rarefaction of the air, while it explains the embarrassment of the breathing, fails to explain the dyspnea and the extraordinary sense of lassitude produced by the least movement.

One of the oldest theories, which still boasts certain adherents (L. Germe), and which will be adverted to later, attributes most of the phenomena observed in rarefied air to the **expansion of the abdominal gases.** This expansion cannot, in fact, be denied; Maissiat gives his views as follow: The pressure of the abdominal gases stimulates the diaphragm and regulates the frequency of its contractions; hence the circulation is more or less dependent on the production of intestinal gases. If the external pressure diminishes, the circulation and the respiration are accelerated, and the blood rushes to the skin; and if the diminution is continued, the animal goes into a state of intoxication and dies. The pressure of the abdominal atmosphere increases, so far as its effects are concerned, in proportion as the external pressure diminishes; and the intestinal gases as they increase in volume distend everything to the point of rupture if the external pressure is rapidly suppressed. The acceleration of the circulation and respiration tends to use up the action of the abdominal muscles more rapidly, and thus brings about a state of rest and equilibrium. Paul Bert objects to this on the ground that the intestine is not to be compared with a swimming-bladder, and that its double communication with the exterior prevents the occurrence of distention. This objection of Paul Bert is certainly open to criticism, although it is based on the results of observations on animals subjected to the action of rarefied air. Morbid tympanism being frequently observed clinically, it must be admitted that the double communication is not an effective obstacle to distention.

In the chapter in which the accidents produced in the organism by **sudden decompression** were described and studied, it was stated that gas is liberated in the circulating blood, and this may give rise to true gaseous **emboli.** The idea of explaining the action of rarefied air by the **liberation or expansion of gases in the blood** and in the humors of the body is very old, and is based on numerous experiments. Robert Boyle, by placing the fluids of the body in a vacuum, succeeded in extracting from them bubbles of gas, and he points out that the liberation of these bubbles in the circulating blood is capable of arresting and disturbing the circulation in innumerable ways. Even when the differences are slight, the aërial particles abundantly retained in the blood naturally distend that fluid, and may thus distend the large vessels and materially affect the rapidity of the circulation of the blood in the capillary arteries and veins. The following explanation by Gavarret expresses a similar idea. The perturbation which accompanies the lowering of the barometric column is in reality a result of pressures exercised from within and from without by vapors and gases imprisoned within the economy. The attention

should be fixed on the gases of the blood which, under the influence of a marked and rapid lowering of the barometric column, may bring on fatal or serious accidents. The blood, in fact, contains in a state of simple solution oxygen, nitrogen, and carbon dioxid. As soon as the external pressure diminishes, these gases tend to escape from the sanguineous fluid, push the walls of the blood-vessels outward, and distend the capillaries in the lungs and in the rest of the body, and these, on account of the tenuity and want of resistance of their walls, may even rupture.

Hoppe-Seyler likewise attributes death to obstruction of the pulmonary capillaries by bubbles of gas, thus causing an arrest of the circulation. According to Hoppe-Seyler, it is the diminution in the pressure and not the deprivation of oxygen that kills; death occurs at the same pressure in air and in pure oxygen, as he has shown by experiments on guinea-pigs; and he concludes that the cause of death is to be sought in the appearance of free gases in the blood. The time of liberation of these gases varies with the pressure, the temperature of the animal, the absorptive power, the affinity of the blood for the gas, and the number of globules. But it has never been demonstrated that this liberation of gas is possible when the diminution in pressure is slight and gradual (Paul Bert). It is to be observed that, according to Fernet's experiments, the gases in the blood are not in simple solution, and do not therefore obey the law of Dalton.

Admitting the analogy between decompression and rarefaction, we may also admit that the theory of gaseous emboli as a cause of death has been indisputably proved when decompression is sudden after the animal had been exposed to a high pressure. But when the diminution, instead of amounting to from 2 to 10 atmospheres, merely amounts to a fraction of an atmosphere, the theory is not quite applicable. In such a case the small quantity of oxygen liberated would be rapidly absorbed by the tissues; in fact, it would be absorbed as fast as it is produced. As regards carbon dioxid, it is readily eliminated by the lungs in the small quantities we are here dealing with; there remains then the nitrogen, which appears to obey the law of Dalton, and probably represents the most dangerous gas in the accidents that occur when a sudden, great lowering of pressure takes place. In the conditions that are now under consideration, however, the proportion of nitrogen in the blood is so small that it cannot, without certain positive proofs about to be detailed, be accorded the least importance. While the positive experiments of Hoppe-Seyler are to be accepted, yet it is quite certain that the conditions are altogether different when decompression is gradual. That investigator experimented on cats, rats, and birds; after subjecting the

animals to the action of sudden decompression down to from 4 to 5 centimeters, he found gas in the vena cava and in the right heart.

To recapitulate: although the liberation of the gases in the blood will in certain cases explain the death of animals exposed to sudden decompression, this factor fails to account for the death of the animals when the decompression or rarefaction is slight and gradual.

EFFECTS OF RAREFIED AIR

Carvallo has made a complete résumé of the effects of rarefied air as shown by the results of modern investigations, and in the general exposition of the subject which is to follow, his work will furnish important details, while Paul Bert's book will be drawn upon for our conclusions. It would be risky to try to apply to the human subject the results obtained by practical experimentation on animals of a single species, for diminution of pressure does not always produce the same effects upon all species of animals—in one it may bring on grave disturbances, while in another the phenomena are quite insignificant.

The diminution of pressure is always relative, and depends on the habitat of the animal under observation. Among aquatic animals two varieties are to be distinguished: those possessed of a swimming-bladder and those which are not provided with that organ. In the former, sudden diminution of pressure, resulting in enormous distention of the gases contained in the swimming-bladder, may bring on death, because the animal has not time either to eliminate the gases through its digestive apparatus, or to absorb them into its blood. In the second class, according to Regnard's experiments, the diminution in pressure seems to be incapable of producing grave disorders or death.

Junod describes as follows the **effects produced in man** when he is placed in a cabinet like the one described for the use of condensed air, and the pressure is reduced to one-fourth of the normal barometric pressure: The tympanic membrane becomes distended, producing a rather uncomfortable sensation, which disappears gradually as equilibrium is re-established. Breathing is embarrassed, the inspirations becoming short and frequent; and at the end of fifteen to twenty minutes this embarrassment of the respiration is followed by actual dyspnea. The pulse is full, compressible, and frequent; all the superficial vessels are in a state of evident turgescence. The eyelids and the lips are distended by the superabundance of fluid. Quite frequently hemorrhages occur, and are accompanied by a tendency to syncope; the skin is uncomfortably hot and its functions are stimulated. The diminished

activity of hematosis; the varying distention of the gases that circulate in the blood; and the superabundance of fluid in the superficial vessels, sufficiently explain the loss of nerve-power, which manifests itself by a lack of energy and by complete apathy. The secretion of the salivary and renal glands is less abundant, and the same effect is noted in the entire glandular system. The body-weight undergoes material diminution.

The modifications brought about in the **various functions** of the body may now be set forth in accordance with the results of the most authoritative investigators.

Respiration.—The respiratory movements become accelerated in proportion as the pressure is lowered. After a certain point has been reached the respiratory rhythm becomes retarded and irregular,* especially if the animal moves about; and in spite of the greater depth of inspiration, which is increased by the slightest effort, evidences of dyspnea and asphyxia soon become apparent, and, if rarefaction is carried still further, death supervenes. The maximum respiratory capacity diminishes: From 17.3, an arbitrary figure assumed for normal pressure, it falls to 11.8 at a pressure of 430 mm., and to 9.9 after the animal has been exposed for half an hour to a pressure of about 420 mm. Lazarus and Schirmunski have observed a marked diminution of the vital capacity. According to Loewy, little change in the respiration is observed until the pressure is reduced to 450 millimeters, when the action of the abdominal gases comes into play, the increase in their volume producing more superficial and more frequent respiration; but if the pressure be diminished still more, the quantity of oxygen in the blood becomes insufficient, the respiratory centers are again stimulated, and the respiration increases in power and in depth.

Circulation.—At first and very soon the contractions of the heart become more rapid, and this acceleration is increased considerably by the slightest movement. Quite frequently hemorrhages occur from the various mucous membranes, especially of the nose and lungs. As in the case of respiration, the phenomena undergo a distinct change if the pressure be still further diminished: the heart beats more slowly, arterial tension falls rapidly, the pulsations become irregular and cannot be felt, and death occurs in diastole.

When the rarefaction does not exceed a certain point, and the sub-

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* In the dog, according to Paul Bert, it appears to be divided into two phases: a thoracic inspiration, followed by a diaphragmatic inspiration.

jects under experiment remain quiet, blood-pressure exhibits only a slight diminution. According to the experiments of Fraenkel and Geppert, the pressure of the blood undergoes little change, and what changes have been observed depend very slightly on any mechanical factor; they have to be explained chiefly by some form of chemical action. Liebig—who in addition to the effect of the expansion of the abdominal gases invokes that of the diminution in the blood-pressure on the pneumogastric nerve and on the elastic tension of the lungs—failed to note any change in the sphygmographic curve. The latter shows no alteration, unless the pulse becomes accelerated and respiration embarrassed.

Lazarus and Schirmunski, who selected instead of the dog the sheep, which is a placid animal *par excellence*, and experimented also on themselves, constantly found that the pulse was accelerated; the sphygmographic curve indicated a diminution of tension or a dicrotism; the pressure of the blood was diminished.

Loewy studied the velocity of the blood-current, and found that it did not augment until the proportion of oxygen became insufficient; the effect of diminution of tension was excluded. The same observation applies, according to this author, to the other modifications observed in the circulatory apparatus.

Digestive Apparatus.—The intestinal gases, when subjected to a diminished pressure, expand according to the law of Mariotte, and one of the first effects of this expansion is vomiting, preceded in man, as in the animal, by distaste for food, nausea, and general malaise. The intestinal distention which is most noticeable in herbivorous animals, in whom it may be great enough to embarrass the respiration, also occurs in man, without, however, producing any serious inconvenience. The subject, nevertheless, feels impelled to unbutton his clothing about the waist. The discomfort is minimized by the fact that the abdominal gases, which cannot escape from a cadaver, are quite readily eliminated through the circulation in the living animal and in man.

Nervous System.—As soon as the pressure has been diminished below a certain point, the animals collapse, fall down on their sides and make continual and ineffectual efforts to get up. If the pressure be diminished still further, consciousness is lost, and at the same time violent convulsions come on, at least in those cases in which the rarefaction has been brought about quite **rapidly.** If the pressure be diminished very **gradually,** death will occur without convulsions; the animals exhibiting complete sensory and motor paralysis. In the case of man the effects, as observed by Paul Bert on himself, are as follow: "When I attempted to raise my leg, after it had been flexed for some time, it was seized with

convulsions which I was unable to control, but which disappeared as soon as I put my foot on the ground. Similar tremors have been reported by aëronauts, who for the most part attribute them to the chilling of the part. Sivel, who experienced these sensations, compared them to the chill that comes on in an attack of intermittent fever. The intensity of sensory impressions is distinctly lessened, and a similar diminution is observed in moral energy and intellectual activity. In one of my experiments I was unable to multiply 28, the number of heart-beats during the third of a minute, by 3. I was forced to content myself with writing the numbers in my notebook. This utter loss of power, however, left me quite indifferent."

Nutritive Exchanges.—The absorption of **oxygen,** as well as the elimination of **carbon dioxid,** diminishes; and this falling-off becomes more and more evident as the pressure is more and more lowered; it is quite noticeable when the pressure is diminished by one-third of an atmosphere. P. Bert obtained the following figures in the case of a sparrow:

	Oxygen Consumed	Carbon Dioxid Eliminated
Normal pressure (76 centimeters),	147 c.c.	122 c.c.
At about 50 centimeters,	118 "	97 "
" " 30 centimeters,	80 "	65 "
" " 24 centimeters,	72 "	57 "
" " 20 centimeters,	60 "	

These figures, as well as those of Fraenkel and Geppert, conclusively prove that the gases of the blood—oxygen and carbon dioxid—are not in a state of simple solution; for if they were, the gas lost by the blood in rarefied air would obey the law of Dalton. Fernet had demonstrated this fact in the case of oxygen, and the experiments of P. Bert show that the same is true for carbon dioxid. In the case of oxygen the greatest loss occurs at a diminution of about one-half of an atmosphere. Below that point the loss of oxygen is small. It appears that the hemoglobin of the living red cells makes an effort to retain a certain quantity of oxygen, so as not to lose its functional characteristics (Carvallo). This phenomenon represents a defensive reaction on the part of the organism.

The combination of carbon dioxid with the alkaline phosphates and carbonates is scarcely more stable than the organic combination of oxygen. As soon as the gaseous tension of the oxygen and of the carbon dioxid is diminished to a certain point, the molecular equilibrium of their combinations is destroyed. This dissociation appears to be greatly assisted by the temperature of the tissues (Sainte-Claire Deville). The

vacuum merely reduces to a minimum the effect of the mass of carbon dioxid and oxygen. Heat then intervenes and finishes the work of destruction which has been begun. This is a general chemical law, and applies in industrial chemistry in the manufacture of quicklime. The carbon dioxid is separated from the lime by means of heat. But this liberation is not produced in an atmosphere of pure carbon dioxid; on the contrary, lime enters into combination with carbon dioxid at a high temperature, so soon as the partial tension of the gas has attained a sufficient height. If it is desired to slake carbonate of lime rapidly and completely, a jet of steam, or other gas, must be passed through it in order to reduce the pressure of the carbon dioxid. Hemoglobin and oxygen behave in a similar manner. In the pulmonary alveoli, where the pressure of the oxygen is high, the hemoglobin becomes completely, or almost completely, saturated with this gas and gives it up again as soon as it comes in contact with the tissues which are greedy for oxygen, and in which the tension of the gas is negative. Heat contributes to this necessary dissociation. This explains the absolute discrepancy between the experiments of Fernet and those of Paul Bert which have just been detailed. The former had carried on all his investigations on the blood *in vitro* and at temperatures much inferior to that of warm-blooded animals. This is proved by the fact that Fraenkel and Geppert, and later Hüfner, arrived at the same conclusions as P. Bert. In fact, these authors found that when the barometric pressure is reduced below half-an-atmosphere, the blood suddenly becomes less rich in oxygen and the proportion continues to diminish as the pressure is lowered.

In spite of the accuracy of the conclusions to be drawn from these figures, the experiments of P. Bert are not altogether unassailable. In the first place, he took no account of the state of nutrition of the subjects on which he experimented; in the second place, his method consisted in analyzing the confined air in which the animal breathed; and, finally, it is difficult in this way to insure absolute rest on the part of the animal under observation. These researches are important enough to deserve repetition with the greatest precautions. Loewy carried on his researches on man inclosed in a medical apparatus; unfortunately, he did not attempt more than a relatively insignificant diminution of pressure. He deduced the following conclusions from his experiments: The interchange of respiratory gases is in a great measure independent of the composition of the inspired air; down to a certain limit the reduction of the barometric pressure has no effect either on the absorption of oxygen and the elimination of carbon dioxid, or on the respiratory quotient. The respiratory mechanism is not influenced, as all the authors

agree; it is only when the pressure of the oxygen in the alveoli becomes less than 400 or 450 mm. that the absorption of oxygen diminishes, while the excretion of carbon dioxid is increased. The experiments of P. Bert have shown that in every case a noticeable diminution in the excretion of **urea** takes place when the animal is confined for several hours in air at a pressure of less than half the normal. According to Fraenkel, on the other hand, urinary nitrogen is augmented. It follows, therefore, that a general diminution in the acts of organic oxidation takes place attended with a weakening of cellular activity.

Fraenkel and Geppert have followed the general method of P. Bert, and have determined the amount of **oxygen,** of **carbon dioxid,** and of **nitrogen** in the arterial blood at normal pressure, and at pressures less than normal, ranging from 470 mm. to 198 mm. of mercury. The lowest pressure at which the proportion of oxygen in the blood remains the same is, according to Fraenkel and Geppert, 460 mm. In one of their experiments, however, the proportion of oxygen was found to be normal at a pressure of 410 mm. In determining the oxygenation of the blood it is necessary to take into account the defensive reaction of the organism, which, by increasing the respiratory rhythm, strives to compensate for the deficiency in the amount of oxygen contained in the respired air. This observation applies to all the figures obtained in those cases, whether they refer to oxygen or to carbon dioxid. Below 366 mm. the quantity of oxygen in the blood rapidly diminishes, and at 198 mm. the deoxygenation becomes so great that life is impossible. In a series of 15 experiments Fraenkel and Geppert once noted an appreciable increase in the amount of carbon dioxid at 452 to 420 millimeters of mercury. In this case the increase was slight; in all other cases there was a diminution varying between 0.48 and 14.94. Below 280 millimeters the diminution becomes more and more marked, showing that organic oxidation becomes more and more insufficient. The quantity of nitrogen was always found to be diminished.

When the pressure is suddenly and greatly diminished, the quantity of **sugar** contained in the blood is increased, and returns to the normal after decompression has been sufficiently prolonged. This difference may be explained as follows: When the blood is suddenly deprived of oxygen, it irritates the liver, and this organ throws into the blood-current a large quantity of sugar, which, if the animal be killed shortly afterward, may be demonstrated by chemical analysis; if, on the contrary, the animal is not killed for some time, the sugar is destroyed in the organism; and as the liver produces less and less sugar, the quantity returns

to the normal, then diminishes still more, and finally disappears even from the liver (Paul Bert).

An important fact which must finally be mentioned is the **lowering of the temperature,** which occurs without the slightest work on the part of the animals, without the air being in the least chilled, and which cannot be attributed to the current of air that must surround the animal to avoid the accumulation of carbon dioxid. The loss of heat usually amounts to 2 or 3 degrees for a diminution of one-half to two-thirds of an atmosphere within half-an-hour; but it varies to some extent with the degree of rarefaction, the duration of the exposure, and the species of animal used for the experiment.

Before seeking an explanation of the modifications observed in the various functions of the organism when subjected to the action of rarefied air, it may not be amiss to inquire what effect the rarefaction of the air has on lower organisms. When **plants** are placed in rarefied air, germination is retarded (Paul Bert). Barley produces fewer stalks than at normal pressure (Dobereimer, de Saussure, Grichow, Barsdin, P. Bert, Godlinoski, Johanssen, Wieler). As the pressure of the atmosphere is lowered, germination becomes less and less active and rapid, and at 7 centimeters germination is abolished. The sensitive plant rapidly loses its sensibility, and dies when the pressure is reduced below 25 cm. Stich, who cultivated plants in rarefied air, noted a gradual disappearance of the carbon dioxid, and found that death occurred from cessation of vital chemical phenomena. These conclusions have been verified by Jaccard and Bonnier. The fermentative power of **yeast** undergoes profound disturbances so soon as the tension of the oxygen is altered, and at a certain point fermentation is entirely abolished. The yeast-cell first becomes inert, and after a certain time suffers permanent death. At the same degree of rarefaction the development of a **chrysalis** becomes impossible, as was observed by Paul Bert, who experimented with silkworms. It appears, therefore, that there is a general law which applies to all vegetable and animal organisms. The **vertebrates,** including man, can live in air of a considerable degree of rarefaction without suffering any notable disturbances of their functions; there is, however, a limit beyond which life becomes impossible. While there is no doubt that individual and tribal resistance is not without influence, it is also necessary to take into account the question of fatigue in the animal under experimentation; in the case of **birds** the occurrence of accidents is materially retarded if the animal has remained inactive; malaise usually appears at a pressure of half an atmosphere, but its appearance will be retarded if the

pressure be very gradually diminished and the animal remain quiet. The more gradual the transition to a lower pressure, the more easily the animal adapts itself; the greater the output of oxygen, the more rapidly the effects of privation of oxygen make themselves felt. In man malaise usually appears as soon as the pressure has been reduced to one-third of an atmosphere. Whenever the pressure of the oxygen within the alveoli is greater than 48 or 50 millimeters of mercury, the vital processes continue as under normal conditions (P. Bert, Loewy, and Bōhr). The minimum air-pressure compatible with life in animals appears to be for all species from 7 to 8 centimeters of mercury. It is a curious fact that it is at this point that germination ceases to be possible. This is certainly more than a coincidence.

The **postmortem findings** in animals who die under these conditions are disappointing. The blood is black everywhere except in the pulmonary veins, where it absorbs oxygen during the period in which the pressure is brought back to normal. It never contains free gas. In mammals the lungs are sometimes emphysematous; in almost all cases there are localized ecchymoses, sometimes, although rarely, associated with actual hemorrhages. A phenomenon mentioned by Paul Bert as characteristic of death under very low pressures is the early appearance and constancy of rigor mortis. Mosso, who is cited by Carvallo, demonstrated that the manner of death when due to lowering of the atmospheric pressure is quite different from the manner of death induced by asphyxia; in the former case there is extreme myosis, in the latter mydriasis; in the former case there is stuporous coma, general numbness, gradual enfeeblement of all the muscular forces, without any previous period of convulsive excitement; in the latter occur constant convulsions, violent arterial excitement, anxiety, and the evacuation of fecal matter and urine.

Theory of Lowered Oxygen Tension

The theories in regard to the mechanical action of pressure, and the theory of production of free gas in the blood, will not be repeated again at this point. It suffices to discuss the theory that the **tension of the oxygen** is insufficient and that this tension is lowered below the vital limit. All living beings, whether vegetable or animal, are incapable of living in a medium in which the oxygen has not a sufficient tension, and the phenomena that have been rapidly passed in review, from simple malaise to death, must be attributed to the diminution of this tension. Certain details must here be considered; not, indeed, in the hope of deriving any useful conclusions in reference to the therapeutic use of

rarefied air in a pneumatic chamber, but simply because the conclusions that we shall reach will be largely utilized in discussing mountain-sickness and balloon-sickness. The general law that has just been enunciated was first demonstrated by the numerous experiments of Paul Bert. His method has been made the subject of various criticisms, and it must be acknowledged that some of these are well founded. But the great number of his experiments, their diversity, and the absolute agreement noted in his results suffice to give them an authoritative character; besides, they have been absolutely confirmed by more recent investigations. If an animal is forced to breathe in a closed space of any convenient size in which the atmospheric pressure can be diminished at will, death is observed to take place before the proportion of oxygen, as shown by the analysis of the gaseous medium, becomes greatly lessened; in fact, despite increase of the proportion as the pressure is more and more diminished. As the experiments referred to were performed in closed vessels, one might be inclined to attribute death either to carbon dioxid or to the toxic products eliminated from the lungs (Brown-Séquard and d'Arsonval). It is hardly necessary to advert to the fact that death occurs in a closed vessel whether the pressure is changed or not. As regards the carbon dioxid it is easy to remove it as fast as it is produced, but the animal dies nevertheless in the same manner and within the same time. On the other hand, when the pressure has become very feeble, death takes place even when the composition of the confined air remains almost the same as that of normal air, and the proportion of carbon dioxid is insignificant. In regard to the toxic organic products eliminated through the lungs, they need not be considered at length in these experiments. In the first place death takes place with too great rapidity to allow these substances to accumulate fast enough to make them effective; and, in the second place, the difference in the capacity of the receiver does not affect the manner of death.

If it be asked, then, whether death is due to a deficiency of oxygen, this question must be answered in the negative, since it has been shown that the gas persists in considerable proportion. It is the **lowered tension of the gas** that is responsible. In the numerous experiments of Paul Bert it was found in every case that death took place when the tension of the oxygen fell to about 3 or 4 centimeters of mercury, whatever might be the capacity of the receiver, and whatever, therefore, the volume of air available for respiration. The truth of this view is proved by the fact that if the tension of the oxygen be raised while the proportion of the gas is increased in the receiver, animals (sparrows) are found to tolerate very low pressures without the slightest malaise. It is therefore an estab-

lished fact that when death occurs in rarefied air from disturbance of the respiration, whether in a closed vessel or in a current of air, it is caused by the diminution in the tension of the surrounding oxygen. Diminution of the barometric pressure is only one of the methods by which this lowering of the tension may be brought about (Bert).

Conclusions

The principal conclusions to be drawn from the experiments of Paul Bert, as summarized by M. Carvallo, are: First, death in rarefied air is due to diminution in the tension of the surrounding oxygen; second, a warm-blooded animal is more sensitive to diminution of barometric pressure than is a cold-blooded animal; third, the higher the body-temperature of an organic species, the more feeble its resistance to diminution of barometric pressure; fourth, the effect of a sudden fall in pressure, however it may be brought about, is less marked when the animal is in repose than when it is in active motion, and less marked in well-nourished individuals than in those who are in a state of inanition; fifth, the higher the animal in the biologic scale, the feebler its resistance to diminution of atmospheric pressure. (The higher the creature is in the biologic scale, the more sensitive it is to any variation in the external air.) Sixth, the animal succumbs sooner when the pressure is suddenly diminished than when the diminution is brought about gradually and methodically. Seventh, low temperatures hasten the occurrence of accidents due to rarefaction.

The **general conclusion** is that all the disturbances, including death, occur as soon as the tension of the oxygen is lowered to the necessary point. The diminution in the barometric pressure is only one of the methods of bringing about this insufficient tension.

The phenomena observed in organisms breathing rarefied air are, in fact, absolutely comparable to the phenomena produced when an animal is only gradually deprived of oxygen. Cellular protoplasm is anaërobic, and it is only after an initial phase of fermentation, during which a number of bodies derived from the albuminous molecule are formed, that oxygen intervenes and brings about a dissociation that causes them to lose their toxicity (Carvallo). So soon as the pressure is lowered beyond a certain point, the tension of the gases becomes too feeble to prevent the dissociation of their combinations (oxygen and carbon dioxid), and it is easy to understand the resulting modifications in the general nutrition and in the various functions. The effect of habit and functional adaptation may be disregarded in this study, as the phenomena referred to take place only when the animal is confined for a short time in

rarefied air. The phenomena that are observed in subjects exposed to low pressures are due to a chemical, not to a mechanical action. When the tension of the oxygen becomes too feeble, its chemical function becomes impossible, and death is then inevitable.

Therapeutic Uses

In conformity with the plan pursued in the case of compressed air, a section should here follow on the therapeutic application of rarefied-air baths. But these baths have been utilized in the pneumatic cabinet only in very exceptional cases, because, since the introduction of cable roads and other systems of mountain railroads, equally good results can be obtained by ascending a mountain, without the slightest fatigue on the part of the patient, at a lower cost in money and annoyance, and under better conditions than in the pneumatic cabinet. If the results are to be compared, the region of low pressure must be reached with the observance of certain conditions, such as absence of the fatigue that would result from mountain-climbing, *i.e.*, on foot, and absence of large variations of temperature—a condition that is readily achieved in closed carriages. Still, mountains are not found everywhere, and the patient must go where they are found, and must go at certain seasons. Hence it would not be without interest to study rarefied-air baths in a pneumatic chamber from the therapeutic viewpoint. There is no doubt that the mode of action of rarefied air is better understood than that of condensed air. It is known that rarefied air acts especially, if not exclusively, on the intimate processes of cellular nutrition; and the application of the action of rarefied air in most of the affections belonging to the group known as nutritional or metabolic disorders certainly has its attractions. In the treatment of these conditions, however, we have too many therapeutic agents at our disposal to suppose that a single one of them should alone prove efficacious.

BALLOON-ASCENSIONS

Theoretically balloon-ascensions constitute the simplest means of obtaining a diminution of atmospheric pressure; there is no fatigue, as in mountain-climbing, and only one new factor—namely, the cold.

General Historical Review

The discovery of the brothers Montgolfier literally opened up new fields; but with their invention it was impossible to reach any great height, and to Charles is due the honor of having been the first to conceive and realize an ascension to the upper strata of the

atmosphere by filling his balloon with a gas lighter than air—namely, hydrogen. Since his day numerous ascensions have been made. It would be too great a task to give a complete historical review of them all; hence only those will be mentioned which were undertaken for scientific purposes. From this point of view **two periods** may be distinguished: one preceding the work of Paul Bert, and closing rather tragically with the death of Crocé Spinelli and Sivel; and the other extending to the present day, when, under the impulse of the great progress made in aërial navigation, the question again excites the interest of physiologists. During the first period, in 1785, occurred the ascension of Blanchard, who noted the cold and the feeling of numbness and weakness; in 1802 the ascension of Sowden, who stated that he attained a height of 15,000 feet and experienced such heat that he was obliged to remove his clothing. Bath, in 1882, on the other hand, had a very different experience; he was the first to give a precise report of the diminution of the temperature which accompanies the increase in the altitude, as measured with the barometer. Finally, the period includes the ascension of Garmin, who experienced nausea and a feeling of general malaise.

The observations of aëronauts cannot be accepted without some reservation; they are always tempted to exaggerate, especially in the matter of the altitude attained, and it is quite evident that many of their estimated figures at least double the probabilities. As Paul Bert facetiously remarks, "a man coming down from such a height can stretch as much as he pleases."

The observations made by Robertson, in 1803, though in some respects open to criticism, are much more exact than any made before his time. He mentions earache and tinnitus aurium, acceleration of the pulse, venous congestion of the face and hands, moral and physical apathy, indifference and somnolence.

Passing with a mere mention the ascension of Zambeccari in 1803, we come to the important observation by Gay-Lussac and Biot in 1804. These aëronauts did not exceed a height of 4000 meters (about 13,000 feet) and accordingly experienced no distress whatever. They observed a considerable acceleration in the pulse. In the second ascension Gay-Lussac attained a height of 7016 meters (about 22,800 feet), and found that his respiration and pulse were greatly quickened; from breathing so rapidly in a very dry atmosphere it is not to be wondered at that the throat became so dry that he found it almost impossible to swallow a piece of bread.

The observations of Glaisher (1862) are quite remarkable for their

accuracy. He made a number of ascensions, of which three are especially interesting from the fact that considerable altitudes were attained. Glaisher believes that the organism rapidly becomes accustomed to rarefied air by a process akin to acclimatization. He found that the number of pulse-beats in the minute increases with the altitude, as does likewise the number of respirations. In his own case the pulse-rate, which was normally about 76 in the minute, became 90 at an altitude of 10,000 feet (say 3000 meters); was 100 at 20,000 feet (say 6000 meters); and rose to 110 when a still greater altitude was reached. The increase in the altitude is not, however, the only factor concerned in the acceleration of the pulse; the state of the individual's health and his temperament are not without influence. A similar relation was observed in regard to the color of the face: at 10,000 feet some individuals exhibit a bright bluish-red color, while others are practically unaffected. At 17,000 feet Glaisher found that his lips were blue; at 19,000 feet both the lips and the hands were of a dark blue color, the beating of his heart was audible and the respiration was profoundly affected; at 29,000 feet he lost consciousness. From all the observations reported by aëronauts it may be concluded that no one is exempt from the effects of extreme altitude; but that the effect varies in the same individual according to circumstances.

It must be noted, however, that in 1867 Flammarion found himself to be very much distressed by the illuminating gas which was escaping from the balloon; and this factor has since been thought to explain in part the accidents observed during very high ascensions.

For a number of years nothing new developed in the history of balloon-ascension until the Société de Navigation Aérienne of Paris again brought the question before the public. One of the most important ascensions was made by Crocé Spinelli, Sivel, Perraud, and Jobert. Their physiologic observations are reported as follows by Dr. Pétard. After speaking of the noises and pain in the ear, he mentions a slight change in the body-temperature, as determined with the buccal thermometer of Sainte-Claire Deville and that of Celsius—it ranged from 35.2° to 37.7° C. (95.4° to 99.8° F.)—and an acceleration of the respiratory rhythm and of the arterial circulation. The latter phenomena were marked in every member of the party, but the relations between them varied greatly in the different individuals. The increase in the respirations averaged about 10 or 12 in the minute, but the increase in the number of pulse-beats varied with the individual's temperament; in the lymphatic subjects it fluctuated between 7 and 11, while in persons of sanguine temperament it ranged from 10 to 13 in the minute.

Pétard was unable to determine with the aid of a pneumodynamometer any appreciable difference in the expansion of the lungs.

Until this period the **theories** advanced in explanation of the phenomena observed in balloon-ascensions were not essentially different from those by which the effects of mountain-sickness were explained, and require no more than a passing mention: the effect of cold, of expansion of abdominal gases, of a distention of the organism from the diminution of the weight supported by the body, the escape of gases from the blood, the diminished proportion of oxygen, and so forth. The only results worth remembering are the observations in regard to the subjective and objective symptoms that are evidently provoked directly by balloon-ascension.

At this time appeared the investigations of Paul Bert, who attributed the accidents observed during balloon-ascensions to impoverishment of the blood in oxygen; these investigations will again be mentioned. Starting out with these new data, Crocé Spinelli and Sivel made some experiments that satisfied them of the value of **hyperoxygenated air** for combating the disagreeable effects of rarefaction, and then undertook some very high ascensions, taking with them oxygen in small cylinders. In their first voyage, made on the 22d of March, 1874, they attained a height of 7300 meters (about 24,000 feet) in two hours. On this occasion they observed an increase in the frequency of the pulse; but none of them was affected with bleeding from the nose, lips, or ears, as Gay-Lussac had reported, although their faces became very red and the mucous membranes almost black. From time to time they experienced flushings of the face and a prickly feeling about the head—sensations which are also observed in the diving-bell. At times the forehead would feel as if it were held in a vise, and there was a sensation as if a slender, hard rod were being forcibly pressed against it just above the brows. These painful sensations almost completely disappeared after a single inhalation of oxygen. The good effects of oxygen inhalations showed themselves in return of the strength and of the appetite, subsidence of the headache, restoration of acute vision and of presence of mind; in fact, all the phenomena observed in the cylinders in Bert's laboratory were reproduced with an unfailing accuracy that under these dramatic circumstances made a profound impression on the two aëronauts; inspiring them with a confidence that they unfortunately pushed to the verge of imprudence, and which ultimately proved their destruction (Paul Bert).

On the 15th of April, 1878, Crocé Spinelli and Sivel, taking Tissandier with them, started on another ascension, and again provided themselves with oxygen, but, as it turned out, in altogether too small amount.

A few passages from the story of this voyage as written by Tissandier are well worth quoting*: "At twenty minutes past one o'clock, at a height of 7000 meters, I inhaled the mixture of air and oxygen, and under the influence of this cordial my failing strength revived; at 7000 meters I wrote on the margin of my note-book as follows: 'I breathe oxygen with excellent result.' At this altitude Sivel, who was physically far above the average and of a sanguine temperament, began to close his eyes from time to time and even to drop off to sleep, and became a little pale. . . .

"I now come to the fatal hour when we were about to be overcome by the terrible influence of the rarefaction of the atmosphere. At 7000 meters we were all standing up in the car; Sivel, who for a moment had been benumbed, felt quite himself again; Crocé Spinelli stood immovable, facing me, and spoke to me of the beauty of the cloud effects. It was indeed a sublime spectacle. Clouds of various fantastic forms, some drawn out, others slightly mammillated, formed a circle of silvery white around about us. Leaning over the edge of the car we seemed to look down into the bottom of a well the walls of which were formed by clouds and, lower down, by mist nearer the surface of the earth, which was just visible in the depths of the atmosphere. The sky, instead of being dark and black, was bright, limpid blue. The sun felt hot on our faces. But the cold nevertheless began to make itself felt, and we had already put on our thickest garments. A numbness had taken hold of us; my hands were like ice; I tried to put on my fur gloves, but without being

* The following observations in regard to pulse, temperature, and respiration are likewise of interest:

Time	Altitude		
12.48	4602 meters	Tissandier, .	110 pulsations per minute.
12.55	5210 "	Crocé, . . .	temperature in the mouth 37.5° C. (99.5° F.).
1.03	5300 "	Crocé, . . .	120 pulsations per minute.
1.05	5300 "	Tissandier, .	number of respirations, determined by Crocé, 26.
"	"	Sivel, ...	155 pulsations per minute.
"	"	Sivel, ...	temperature in the mouth 37.9° C. (100.2° F.).

For comparison the following figures represent the average of a number of observations taken on several consecutive days before the ascension:

	Pulse	Respirations	Temperature in the Mouth
Crocé Spinelli, ...	74 to 85	24	37.3° C. (99.1° F.).
Sivel, ...	76 to 86	not taken	37.5° C. (99.5° F.).
Tissandier, ...	70 to 80	19 to 23	37.4° C. (99.4° F.).

aware of it the action of merely taking them from my pocket necessitated an effort that I was incapable of making. At this altitude, 7000 meters, I was writing almost mechanically in my note-book, from which I copy the following lines word for word; I have no recollection of having written them, and they are in fact almost illegible, having evidently been written by a hand which shook with cold: 'My hands are frozen. I am well; we are all well; mists on the horizon with little round clouds. We are ascending. Crocé is blowing. We are breathing oxygen. Sivel is closing his eyes, Crocé also closes his eyes. I drain the aspirator. Temperature —10° C. (14° F.) at 1.20 P. M., barometer at 320. Sivel is asleep. 1.25 P. M.: temperature —11° C. (12.2° F.); barometer 300. Sivel throws out ballast. Sivel throws out ballast.' The last few words are almost illegible. Sivel, who for several minutes had been motionless and apparently lost in thought, closing his eyes from time to time, had evidently just remembered that he wished to pass beyond the point then attained by the 'Zenith.' He rose to his feet, his stalwart figure suddenly took on an unaccustomed buoyancy, and turning to me he said, 'What is the pressure?' 'Thirty centimeters (about 7450 meters altitude).' 'We have plenty of ballast; shall I throw out some?' I answered: 'Do as you like.' He turned to Crocé and asked him the same question. Crocé inclined his head in sign of assent. There were at least five bags of ballast in the car and as many more were suspended from the sides by short cords. The latter were already partially emptied. Sivel could no doubt have told their weight, but it is now impossible for me to give any exact report of what it was. Sivel took his knife and cut three of the cords, one after the other. Three bags emptied their contents and we rose rapidly. The most distinct recollection I have of the ascension refers to something which happened just before the emptying of the ballast bags. Crocé Spinelli was sitting down and holding in his hand the cylinder of oxygen, his head slightly bent and apparently much oppressed. I still retained strength enough to tap the aneroid barometer with my finger to hasten the movement of the needle; Sivel was just raising his hand to the sky as if to point out to us the higher regions of the atmosphere. I kept perfectly still, without, however, realizing that I had in all probability lost the power of movement. At 7500 meters the numbness experienced is extraordinary; body and mind gradually become weaker and weaker, so gradually and so insensibly that the individual is quite unconscious of the process. There is not the slightest suffering; on the contrary, there is a feeling of perfect content, apparently the effect of the surrounding flood of light. One becomes utterly indifferent, without a thought for the dangers of the situation. The

balloon continues to ascend and one feels glad to ascend with it. The so-called vertigo of the upper regions is more than a mere phrase; but, so far as I am able to judge from my own impressions, this feeling of vertigo appears at the last moment, just before the sudden, unexpected, irresistible annihilation. After Sivel had cut the bags of ballast, at an altitude of 7450 meters and a pressure of about 300 millimeters—which is the last figure that I wrote in my note-book—I seem to remember that he sat down on the floor of the car in the same position as Crocé Spinelli. I was propped up in a corner of the car, where I managed to sit up with the support which it afforded me. Very soon I began to feel so weak that I was unable to turn my head and look at my companions. I tried to take hold of the cylinder of oxygen, but I found it impossible to raise my hand; nevertheless my head was perfectly clear; I kept looking at the barometer with my eyes fixed on the needle, which soon reached the figure 290, then 280, and still continued to move. I tried to cry out 'we are at 8000 meters,' but my tongue was paralyzed. Suddenly I closed my eyes and fell unconscious, absolutely losing my memory. It was about half-past one. At 8 minutes past 2 I woke up for an instant. The balloon was descending rapidly. I was just able to cut one of the ballast bags to check the rapidity of its descent and to write on the edge of my note-book the following lines, which I copy: 'We are descending. Temperature —8° C. (17.6° F.). I throw out ballast; barometer at 315. Sivel and Crocé are still lying in a faint on the floor of the car. We are going down very fast.' I had barely written these lines when I was seized with a kind of tremor and again fell in a faint. A strong wind was blowing from below, showing that we were descending rapidly; a few moments later I felt myself shaken by the arm and recognized Crocé, who had regained consciousness. 'Throw out some ballast,' he said, 'we are going down.' But I was barely able to open my eyes, and I did not see whether Sivel was also awake. I remember that Crocé detached the aspirator, which he threw overboard along with some ballast, some blankets and other articles; but my recollection of all this is extremely vague, and I evidently relapsed into more complete stupor than before. It seemed to me that I was beginning an eternal sleep. What happened after this I cannot tell; it is certain that the balloon, relieved of its ballast, impermeable as it was, and filled with heated gas, must have ascended once more into the upper regions. At half-past three I again opened my eyes, and although I felt completely prostrated my mind began to clear. The balloon was falling with a terrible velocity; the car was swinging from side to side in wide oscillations. I dragged myself on my knees and pulled Sivel and Crocé by the arm. 'Sivel! Crocé!' I cried,

'wake up!' My two companions were crouching in the car, their heads covered by the traveling rugs. I summoned all my strength and tried to raise them. Sivel's face was black; his eyes were glazed, his mouth wide open and filled with blood. Crocé's eyes were half closed and his mouth was bloody. Our descent took place in the plains surrounding Ciron (Indre) at a distance of 250 kilometers from Paris as the crow flies. . . . .

"Having told the story of the ascension of the 'Zenith,' I come to the two important questions that have excited such lively interest in the scientific world and among the general public. What was the greatest height attained? and what was the cause of the death of Crocé Spinelli and Sivel? The first question has been solved by opening the barometric tubes devised by Jansen and used by Sivel and Crocé Spinelli in their earlier ascension, in 1874, when they reached an elevation of 7300 meters (about 24,000 feet). One tube had been broken; several others had either been injured in some way or had failed to work; but the remaining two had worked perfectly, and these give identical results. They establish the fact that the lowest pressure reached was between 254 and 262 millimeters, making, after correcting for pressure on the surface of the ground, the greatest height attained between 8540 and 8601 meters. As at the instant when I lost consciousness, at 8000 meters, the needle of the barometer was moving rapidly past the number indicating a pressure of 280 (8002 meters), showing that the balloon was rising with considerable speed, I am convinced that we attained the altitude of 8600 meters (say 28,000 feet) at the first ascent. After the first descent Crocé Spinelli, and certainly Sivel, were still living; they must have expired when the balloon for the second time rose to the level from which it had shortly before descended, and which it could not exceed on account of its weight and volume. It seems to me beyond a doubt that the death of my unfortunate companions was due to the rarefaction of the atmosphere. The action of this extreme tenuity may be borne for a short time; but to resist its effect for two hours at a stretch presupposes enormous powers of resistance. We were much longer in the upper regions than other aëronauts who ascended to the same altitudes. I may add that the extreme dryness of the air may have had something to do with the fatal result. The question will naturally be asked, why I survived. I probably owe my life to my peculiar temperament, which is essentially of the lymphatic type, and perhaps also to the fact that I lost consciousness completely, and therefore suffered an absolute suspension of the respiratory function. I began the ascension with my stomach empty, and I first thought I was alone in that

respect; but it has since been proved that although Sivel may have eaten, Crocé, like myself, had practically nothing in his stomach.

"At an altitude of 8600 meters (28,000 feet) the rarefaction of the atmosphere is very great, since the mercurial column of the barometer measures not more than 26 centimeters. I am convinced that Crocé Spinelli and Sivel would still be alive, in spite of their prolonged stay in the upper regions, if they had been able to inhale oxygen; they probably lost the power of movement suddenly, as I recognized in my own case, and the tubes conveying the vital air must have fallen from their paralyzed hands. But these noble victims have opened up new horizons for scientific investigations; these soldiers of science, in the hour of their death, have pointed out the perils of the way, and have thus enabled their successors to guard against these perils."

The tragic end of this voyage made a profound impression, and the first effect was to raise a doubt as to the truth of Paul Bert's theory—the argument being made principally by Colin, of the Académie de Médecine. It also produced a crop of so-called protective devices of absolutely no practical value. Another effect was that all physiologic research in regard to the effect of high altitudes attained in balloon-ascensions was for the time abandoned; and we now come to the contemporary period, when these interesting questions have again excited the zeal of physiologists.

The first ascension in the **second** or **contemporary period** is that of Gross and Berson in 1894 in the 'Phœnix.' Lazarus, after giving an epitome of the facts observed by these aëronauts, deemed it necessary to add that from a scientific as well as from a practical viewpoint their ascension must be considered better planned, and carried out in a truer scientific spirit, than the ascension of Crocé Spinelli and Sivel. He forgets, however, that the German aëronauts made their voyage ten years later, profiting by the lessons and experience of their predecessors as well as by the improvements in the various instruments used for making observations; and, finally, that they did not go beyond the height of 8000 meters. Gross and Berson used instruments that were impervious to the action of the solar rays, and thus were able to note a temperature of —36.5° C. (—33.7° F.) and to make certain other interesting meterologic observations. Above 5000 meters (16,500 feet) they experienced palpitation of the heart and dyspnea on the slightest exertion. Like the French aëronauts, they found that they could renew their strength by inhaling oxygen. At 7000 meters (23,000 feet) they shook with spasmodic tremors due to cold and weakness, and observed cyanosis. The stomach refused tea and the inhalation of oxygen provoked nausea. Although consciousness was perfectly preserved, there was an absolute

want of energy, so that they could not even put on the fur garments within their reach. At 8000 meters (24,000 feet) the weakness continued to increase in spite of inhalations of oxygen, sight became dim, and the aëronauts found that they needed all their energy to stand up and make the necessary observations. Gross, who enjoys a large experience in aërial voyages, asserts that physical fatigue increases in proportion with the altitude, and that the feeling of absolute annihilation which overcomes the aëronaut at a certain height is by no means painful; he compares it to the feeling experienced while falling asleep. The intensity of the disagreeable sensations depends upon the rapidity of the ascent. On the whole, there is nothing new, nothing that has not been described before, in the report of their ascension.

PHYSIOLOGIC EFFECTS OF LOW BAROMETRIC PRESSURE

Contemporary investigators have occupied themselves chiefly with the study of **sudden variations** in pressure such as are experienced in balloon-ascensions; observing the physical and chemical phenomena of respiration; the arterial tension, and the composition of the blood. In this connection reference may be made to the researches of Hallion and Tissot on the chemical modifications of respiration, on the gases of the blood, and on arterial tension; to the researches of Calugaréanu and Henri, Jolly and Beurande, on the composition of the blood; and to Bourier's studies on the disturbance of labyrinthine compensation.

Insufficient Absorption of Oxygen.—It is not our purpose merely to describe and to explain, if possible, the grave phenomena known collectively by the name of **aëronauts' disease**; but rather to present in rapid review the various physiologic modifications observed in balloon-ascension even in the absence of subjective sensations. According to Paul Bert and his followers, the whole question resolves itself into the insufficient absorption of oxygen, which is due to the lowered tension of the gas in the air respired. Owing to this lowered tension the oxygen fails to enter the blood—and therefore the tissues—in sufficient quantity to keep up to their normal degree of efficiency the vital combustions of the body. Two different classes of phenomena must thus be distinguished when the organism is subjected to a sudden rise or fall of the barometric pressure such as takes place in balloon-ascension. The first belongs to the **initial period,** and the phenomena are the expression of the **struggle** on the part of the organism to defend itself by various reactions against the sudden and increasing deprivation of oxygen; the other belongs to the **second period,** and the phenomena indicate the **defeat** of the organism, which has

become incapable of continuing the battle owing to the progress of intoxication by the waste products that are not burnt up in the tissues. We are chiefly interested in the **first group** of phenomena; for if balloon-ascensions are ever to be utilized as a method of therapeusis, it is evident that the ascension will not be continued beyond the initial period. Owing to the low barometric pressure, the tension of the oxygen is diminished, and therefore oxygen absorption is reduced, all other conditions remaining the same. This point is undeniable; it is a physical truth which cannot be assailed. The organism, by the mere fact of its being alive, must react; and this reaction—consisting in an acceleration of the respiration and circulation—has for its object to prevent the deoxygenation of the blood and of the tissues. The question is, At what point will this defensive reaction become insufficient? The answer is furnished by an analysis of the **gases of the blood.**

Paul Bert was the first to attempt accurate measurements of the modifications that take place in these gases at different barometric pressures. He made 23 measurements at pressures varying from 57 to 7 centimeters of mercury, taking the blood either from the femoral artery or from the carotid artery (of the dog). He noted, first of all, marked differences in the proportion of oxygen in the blood of different animals under conditions as nearly comparable as possible; he also made a similar observation in regard to carbon dioxid. This is a general law, and is explained by some inequality in the amount of hemoglobin contained in the same quantity of blood, or in differences of saturation in the hemoglobin. Under normal conditions the normal blood is almost never saturated with **oxygen,** and the amount obtained is quite variable. Some individuals, by increasing the frequency and depth of their respirations, are able at will to cause a rise in the percentage of oxygen; others, again, are unable to do this. It follows that all subjects are not in identically the same conditions when they are subjected to a diminution of the barometric pressure. Young animals and animals suffering from disease have a much smaller quantity of oxygen in their arterial blood. In every case the quantity of oxygen and carbon dioxid in the arterial blood diminishes as the barometric pressure falls; but this diminution is not constant in different animals for the same diminution of pressure. Disregarding these individual variations, it is found that on the average the arterial blood at a pressure of 56 centimeters contains 13.6 per cent. less oxygen than under normal pressure; at a pressure of 46 centimeters, 21.1 per cent. less; at a pressure of 36 centimeters, 43 per cent. less; and at a pressure of 26 centimeters, 50.7 per cent. less. Thus at a pressure of 26 centimeters, on the average, one-half of the oxygen in the blood dis-

appears. These figures show that the diminution of oxygen does not by any means follow the law of Dalton, which for the same degrees of barometric pressure would yield diminutions of 26.3, 39.4, 52.6, and 65.8 per cent, respectively.

The mean diminution of **carbon dioxid** for the same degrees of barometric pressure is 10.9, 14, 29.2, and 58.2 in a hundred parts of gas at normal pressure. This shows an even greater variation from the law of Dalton. The average loss in carbon dioxid is less than the loss in oxygen, from which it follows that the combination of hemoglobin is apt to become partially destroyed, to undergo dissociation even when the barometric pressure is only slightly diminished. This dissociation becomes manifest when the pressure has been diminished by 20 centimeters, or, in other words, at a pressure of 56 centimeters. It continues to increase as the pressure falls, and at about half an atmosphere the loss of carbon dioxid is found to be greatest. It is probable that most of the carbon dioxid in arterial blood is in very unstable combination with the alkaline phosphates and carbonates. The normal proportions of oxygen and carbon dioxid are rapidly restored—in three-quarters of an hour or less—after the animal is brought back to a pressure of 76 centimeters. The conclusions arrived at by Fernet in regard to the constancy of the proportion of oxygen chemically bound to the blood without regard to variations of pressure (97.22 per cent.) are true only under the conditions of pressure and temperature with which this author worked. At higher pressures and at the temperature of the body, the proportion of oxygen really follows all the modifications of pressure, although less rapidly than a gas in solution would do. Moreover in the living subject this is complicated by the fact that the blood is insufficiently agitated in contact with the air; so that the diminution in the quantity of oxygen is much more rapid than would be indicated by experiments *in vitro* such as Fernet's.

The experiments of Paul Bert have since been repeated by a number of observers. His method of obtaining the blood and of extracting the gas have been criticized. Without speaking of the researches of Hüfner, which tally with those of the French savant, there are certain others that, we believe, have been carried out after a method which defies the criticism of Fraenkel and Geppert. Down to 41 centimeters (according to Bert, 56 centimeters) the proportion of oxygen and carbon dioxid is not materially modified; the differences noted in 8 experiments, with pressures ranging from 41 to 47 centimeters of mercury, are very small, and in some instances zero or even minus; on the other hand, the nitrogen is found to be constantly diminished, but the diminution is not

proportionate to the degree of rarefaction. It is probable that within these limits the increased respiratory activity suffices to maintain the normal equilibrium. From 37.8 to 36.6 centimeters there is a constant diminution of oxygen and carbon dioxid; for oxygen from 1.95 to 6, and for carbon dioxid from 0.48 to 8.4. The diminution is not proportionate to the degree of rarefaction, a fact which Paul Bert had observed and explained by the variation in the power of different individuals to resist the diminution in the tension of the oxygen by increasing the depth and frequency of the respiratory movements. It is also to some extent due to the differences in the quantity of oxygen normally taken up by the tissues in different individuals.

But to return to the experiments of Fraenkel and Geppert. Between 31 and 19.18 centimeters, that is to say, at a pressure considerably lower than half an atmosphere, the blood is greatly impoverished both as regards oxygen and carbon dioxid, the diminution of oxygen being from 5.76 to 13.09. The oxygen diminishes regularly with the pressure, while the carbon dioxid, on the other hand, exhibits a much more irregular curve except when the pressure is extremely low,—from 25.3 to 19.8 centimeters,—when, owing to the insufficient quantity of oxygen, less carbon dioxid is formed in the tissues. When the pressure falls below a quarter of an atmosphere, death supervenes.

Recently Hallion and Tissot, who made a solitary experiment with a dog which they took with them in a balloon, obtained quite different results, which may be summarized briefly. Up to 3500 meters the **oxygen** and **carbon dioxid** contained in the blood, instead of following the laws governing the solution of gases, behave in exactly the opposite manner. The **nitrogen** contained in the blood follows the laws of the solution of gases; that is to say, it escapes from the blood as the altitude increases and the barometric pressure falls. At the level of the earth 100 cubic centimeters of blood contain 3.25 cubic centimeters of nitrogen; at 17.50 meters, 2.135 cubic centimeters; at 3500 meters, 0.525 cubic centimeters. The **total quantity of gases** contained in the blood, however, increases with the altitude, which augmentation is due to increase in the quantity of **oxygen** and of **carbon dioxid.** At the level of the earth the blood contains 15.5 cubic centimeters of oxygen for every cubic centimeter of blood; at 1750 meters, 18.41 cubic centimeters; at 3500 meters, 19.97 cubic centimeters; and the number returned to 17.7 cubic centimeters at an altitude of 800 meters during the descent. In regard to the carbon dioxid, the proportion at the level of the earth was found to be 48.49 cubic centimeters; at 1750 meters, 51.13 cubic centimeters; and at 3500 meters, 60.38 cubic centimeters. These figures, however, were not

obtained at the altitudes mentioned; the blood that is collected in the balloon cannot be examined until the observer returns to the laboratory, when it is already considerably modified and presents a blackish discoloration. The authors, it is true, attempted to verify their figures by comparison with a control experiment; nevertheless their conclusions, which differ entirely from those obtained by earlier investigators who made numerous observations under the best possible conditions, must be received with a great deal of reserve on account of the unsatisfactory conditions under which the analyses were made. Besides, Hallion and Tissot took no account of the variations in temperature, which have such an important influence on the analysis of gases. Until these results, therefore, are confirmed by other investigations, the conclusions of Paul Bert and those of Fraenkel and Geppert will have to be accepted.

Effect on the Blood.—It has been shown how the organism, when obliged to breathe air in which the oxygen tension is insufficient, resorts to the defensive measure of increasing the frequency and depth of the respirations. There is also another defensive process, which undoubtedly takes place when the organism has sufficient time to react, as, for instance, during a stay in the mountains; it is an augmentation in the **respiratory capacity of the blood** consequent upon an elevation in the percentage of hemoglobin which may be accomplished either by enlargement of the **volume** of the **red blood-cells,** or, what is more probable, by increase in their **number.** It is questionable, however, whether this takes place in a short balloon-ascension.* To answer the question let us examine the figures and observations reported by various authors: Miescher observed an increase of the red blood-cells above the normal within a few hours during a mountain-ascension; Mercier found an evident excess in the number of red blood-cells at the end of eleven hours; and numerous mountain-climbers have reported similar experiences. Observers of unquestioned authority have observed a considerable increase, amounting to from 10 to 30 per cent., in the number of red blood-cells coming on during the time occupied by a balloon in ascending to a height of 3000 or 4000 meters, or, in other words, during one or two hours. Calugaréanu and V. Henri, in their ascension of November 20, 1901, made a blood-count on three dogs, one of which had suffered splenectomy. The blood was taken from a vein in the ear, and the following figures were obtained:

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* It is by means of this biologic mechanism that the inhabitant of the plains arms himself against mountain-sickness; but it presupposes an essential factor—time (Fromont de Bouaille).

Dog A, normal:

Number of red blood-cells at sea-level, ...	7,874,000	
" " " " 2200 meters, . .	8,944,000	—increase of 14%.
" " " " 3000 meters, . .	9,880,000	—increase of 26%.

Dog B, normal:

Number of red blood-cells at sea-level, ...	7,648,000	
" " " " 3000 meters, . .	8,972,000	—increase of 17%.

Dog C, splenectomized:

Number of red blood-cells at sea-level, ...	7,928,000	
" " " " 2200 meters, . .	8,356,000	—increase of 5%.
" " " " 3000 meters, . .	8,892,000	—increase of 11%.

The pressure at 2200 meters (about 7200 feet) was 780 millimeters of mercury; at 3000 meters, 520 millimeters. The temperature, when the thermometer stood at 12° C. (53.6° F.) at the level of the earth, was zero (32° F.) at 3000 meters (about 10,000 feet).

J. Gaule, of Zürich, had already observed a marked increase in the number of red blood-cells under the same conditions. At the meeting of the Académie des Sciences de Paris, held on the 25th of November, 1901, J. Gaule stated that he had found in two balloon-ascensions, at an altitude between 4200 and 4700 meters, the number of his own red blood-cells to exceed 8,000,000. In addition, he reported an observation which thus far has not been confirmed by others—namely, that blood-preparations made at 4000 meters after the method of Ehrlich, and stained with eosin and hematoxylin, contained numerous nucleated red blood-cells. Many of the nuclei were in a state of segmentation, and groups of three or four corpuscles were found, suggesting the occurrence of subdivision. In the blood of the same subject, prepared in the same way before the ascension, nothing of the kind had been found. Gaule therefore concludes that new erythrocytes are produced during balloon-ascensions even when the ascent is very rapid.

Jolly, in his ascension of the 21st of November, 1901, attained a height of 4450 meters within one hour and twenty minutes. Blood-preparations were made from one of his companions, Bonnir, with the following result:

Time			Number of Erythrocytes	Number of Leucocytes
12.30,	on the ground,		4,760,000	6800
1.50,	1100 to 1600 meters,		5,450,000	7200
2.15,	3000	"	5,060,000—during the passage through a layer of clouds	5200
2.40,	4000	"	5,210,000	5200
3.02, (—4° C., 24.8° F.)	4450	"	5,330,000 (increase of 12%)	9200
During the Descent				
3.15,	below 3900	"	4,750,000	5600
[illegible]	2600	"	4,800,000	7600

The **percentage of hemoglobin** determined with Malassez's colorimeter was found to be 14 at the level of the ground, 15.5 at the greatest height attained, and 14 during the descent, giving a constant and normal **quantity** of hemoglobin of 29.1. The **number of leucocytes** attained its maximum at the greatest elevation, although there was never a true leucocytosis.

	Percentage of Lymphocytes	Percentage of Large Mononuclear Leucocytes	Percentage of Polynuclear Leucocytes	Percentage of Eosinophilic Leucocytes
On the ground, ...	19.0	7.0	73.5	0.5
At 4450 meters, ...	18.5	3.5	78.0	0.0
At 2900 " (descent), .	19.0	5.0	76.0	0.0

The proportion between the different corpuscular elements is therefore essentially the same. Jolly failed to find any nucleated red blood-cells in any of his preparations. He observed no change in the volume of the colored cells, no poikilocytosis, nor any increase in the number of microcytes or free granules. There is therefore no appreciable histologic change in the blood except the increase in the number of colored cells; the latter in this observation, as well as in those of Calugaréanu and Henri, in which it varied in the different dogs examined, bears no relation to the altitude. The blood was obtained from the finger.

Bensaude adopted a different technic in order to avoid the error due to contraction of the peripheral vessels or to evaporation of the drop as it is taken from the finger. In his ascension of the 28th of November, 1901, he rose to a height of 4400 meters in two hours. First he measured the volume occupied by the red globules in the entire body of the blood extracted from the carotid artery. After defibrinating or oxalating the blood in a hematocrit with two pipettes, one containing the blood taken at the level of the earth, the other the blood taken during the voyage, he centrifugated it and observed that between 2000 and 3000 meters the volume occupied by the corpuscles in the two pipettes was the same, whereas between 4000 and 4400 meters the sample taken at that elevation showed an increase of 4 to 6 per cent. This increase persisted to the extent of 2 per cent.* after the return to the earth.

* According to Ambard, the hematocrit is liable to an error of sometimes 2 per cent. and sometimes 4 per cent.

The **density of the blood** also undergoes a slight increase.

Between 2000 and 2300 meters	temp. $-3°$ to $+5°$ C. 26.6° to 41° F.	1.06110
" 4000 " 4400 "	temp. 3° to 5° C. 37.4° to 41° F.	1.06525
On the ground after the descent	temp. 0° C., 32° F.	1.06012

As regards the **volume of the corpuscles** there is no appreciable difference; the number of smaller cells especially, contrary to the assertion of Viault, is low.

	On the Ground	Between 4000 and 4400 Meters
Corpuscles measuring more than 7.5 μ, . . .	4.24	2.4
" " from 7 to 7.5 μ, . . .	78.39	82.4
" " " 6.5 to 7.0 μ, . .	10.59	11.2
" " " 5.0 to 6.5 μ, . .	5.93	3.2
" " less than 5 μ, ...	0.85	0.8

In spite of the most conscientious search, Bensaude was unable to find a single nucleated red blood-corpuscle, and thus failed to confirm the findings of Gaule. There was little variation in the proportion of different varieties of white cells.

	On the Ground	Between 4000 and 4400 Meters	On the Ground after the Descent
Polynuclear, ...	75.49	72.33	64.89
Mononuclear (clear), . . .	9.28	5.33	7.31
Mononuclear (opaque), . .	14.43	21.54	22.58
Eosinophiles, ...	0.80	0.79	0.22

The hematoblasts examined in preparations of human blood and of pigeon blood showed no notable modification.

These figures give a wide variation from the numbers of colored cells in the peripheral vessels obtained by other investigators; thus, Gaule found an increase of 63 per cent., Jolly of 12 per cent., and Bensaude of only 4 to 6 per cent. The question was again taken up by Ambard, who made experiments on animals exposed to rarefied air in boxes. The blood-count was made with Hayem's hematometer and the volume of the corpuscles was determined with the hematocrit. By means of various ingenious contrivances, resembling in a measure those adopted by Paul Bert, Ambard surrounded himself with the best possible conditions for observation. The blood was taken from the femoral artery. As shown in the table on page 145, a degree of rarefaction corresponding to 45 centimeters of mercury, continued for from half-an-hour to an hour, proved insufficient to produce an appreciable increase in the number of red cells in the blood taken from the central circulation.

EFFECT OF RAREFIED AIR ON BLOOD FROM FEMORAL ARTERY

	Number of Erythrocytes		Volume of Erythrocytes	
	Normal Pressure	Pressure of 45 cm. of Mercury	Normal Pressure	Pressure of 45 cm. of Mercury
Dog weighing 8.51 kilograms—pressure reduced in 32 minutes, .			100	101.6
Dog weighing 5.5 kilograms—pressure reduced in 35 minutes, . .	6,400,000	6,176,000	100	100.0
Dog weighing 6 kilograms—pressure reduced in 25 minutes, and maintained additional 35 minutes,	5,520,000	5,456,000	100	104.0
Dog weighing 8.2 kilograms—pressure reduced in 30 minutes, . .	4,544,000	4,672,000	100	98.2
Dog weighing 10 kilograms—pressure reduced in 1 hour and maintained additional 55 minutes, . .	7,512,000	7,450,000	100	96.0

Caligaréanu and Henri determined the density of the blood taken from the femoral artery by the bottle method, using 14 cubic centimeters of blood, and found that it was 1061 at the level of the earth, and 1062 at the height of 3200 meters; that is, a smaller difference of density than even that observed by Bensaude, and thus practically negligible. They also determined the total quantity of nitrogen and of iron, and found:

On the ground, . . . 3.16 grams of nitrogen in 100 cubic centimeters of blood.
At 3200 meters, . . . 3.14 " " " " " " " " "
On the ground, . . . 0.56 " " iron " " " " " "
At 3200 meters, . . . 0.53 " " " " " " " " "

The **conclusion** to be drawn from all these figures is that the blood taken from the femoral artery, in regard to its percentage of water, nitrogen, and iron, is practically the same as the blood taken at the level of the earth before beginning the ascension; the differences are well within the limits of the possible errors of such experiments. The reason for the marked differences in the results obtained by several different authors of equal ability will be investigated later. Except that some of them used peripheral and others central blood the conditions of the experiments were identical, and the absolute contradiction between the results obtained by the same authors in the same experiment (Caligaréanu and Henri) is truly remarkable.

The **reduction-time of the oxyhemoglobin** during balloon-ascensions has also been studied. Vallot had observed that this underwent an almost instantaneous diminution. The question was again taken up by Reymond in his ascension of the 19th of November, 1901. The **quantity** of oxyhemoglobin augmented rapidly; in less than an hour, at

a height of 3600 meters (about 11,800 feet), the increase amounted to from 10 to 14 per cent. In addition, the **intensity** of the reducing process was practically doubled between 1000 and 1900 meters (say 3000 to 6000 feet). As a corollary the reduction-time was diminished by one-half. During this ascension the aëronauts experienced no vertigo, dyspnea, or cyanosis. Reymond, like the observers who reported an increase in the number of colored cells, confined himself to the examination of the peripheral circulation; the time occupied in reduction was estimated by examining the thumb.

The inevitable conclusion, which Fromont de Bouaille does not hesitate to formulate after Ambard, is that during balloon-ascensions the number of red blood-cells is considerably increased, and this increase is accompanied by a proportionate increase in the percentage of hemoglobin; nevertheless the increase in the colored cells is a purely **local** phenomenon, and does not affect the entire mass of the blood, since it is not found in blood taken from the central circulation.

How, then, shall this **peripheral polycythemia** be explained? Long ago Malassez determined that under a great variety of local influences a **local polycythemia** could be produced. Thus, intense and persistent polycythemia can be induced in the rabbit by section of the sympathetic; a slight pressure applied to the ear of a rabbit suffices to cause a considerable polycythemia which lasts as long as the pressure is kept up; and, finally, what is much more important in the present connection, the exposure of the ear to cold is followed by the same phenomenon. Therefore when several successive blood-counts are to be made on an animal for purposes of comparison, the animal must either be placed in the thermostat or the part from which the blood is to be taken must be vigorously irritated so as to bring the circulation to its maximum of activity. The differences in the number of corpuscular elements in the blood may be quite considerable under certain circumstances. If, for example, the rabbit's ear is laid on a cushion of absorbent cotton saturated with water at 40° C. (104° F.), and then on another cushion saturated with ether which is made to evaporate rapidly by passing a current of air over it, a variation of 50 to 70 per cent. in the number of red blood-cells may be observed. If heat and cold can thus affect the local circulation, it is readily comprehensible that the results of observers who use blood taken from the peripheral integument must be accepted with a great deal of reserve; and when it is recalled, in addition, that the temperature in balloon-ascensions often undergoes variations of from 10° to 15° C. (18° to 27° F.), one is strongly tempted to regard the polycythemia reported by the authors cited in the foregoing résumé as a purely local vasomotor

phenomenon (Fromont de Bouaille). It is indeed impossible to disregard the marked influence of cold and the peripheral vasoconstriction resulting therefrom in all the phenomena observed during balloon-ascensions.

Although I have had no personal experience in the matter, I may be permitted to risk an hypothesis. The occurrence of polycythemia in individuals who have been only a few days at some elevated station in the mountains is a phenomenon which, as will be seen later, must be regarded as established beyond a doubt. The number of blood-cells present in any given part at different moments must also be considered as quite variable—and the variations are in direct relation with the needs of the organism. It may therefore be assumed that in the presence of a rapid lowering of the pressure such as takes place during a balloon-ascension and is always accompanied by a considerable fall in the temperature the organism reacts and defends itself in the same way as when an individual is suddenly transferred to the conditions prevailing at the top of a mountain. In the latter case a general polycythemia makes its appearance, which clearly could not be due to reproduction within the short time occupied by a balloon-ascension; but the organism sends out its existing reserve of colored cells toward the periphery, and this mobilization is no doubt largely effected by the action of the cold—particularly by its stimulation of the vasoconstrictors. Whatever may be the mechanism, however, the reaction is the same; when the oxygen becomes less abundant and its tension insufficient, the composition of the blood undergoes a modification which makes it more greedy of oxygen, that is to say, more rich in hemoglobin, or, finally, more heavily charged with red blood-cells.

In order finally to dispose of the question of the circulation and thus avoid any future repetition, it will be well to review the effects of a diminution of the barometric pressure on the arterial tension, the frequency of the pulse, and the velocity of the blood.

Effect on Blood-pressure.—Paul Bert states that he was unable to make extended or accurate observations on animals in pneumatic chambers on account of the clots that formed in the arteries and in the apparatus; but in the few observations that he was able to make he found that there was very little diminution in the tension. Only in rare instances, even when he used very low pressures and brought about the rarefaction very rapidly, did he observe pulmonary or nasal hemorrhages. Fraenkel and Geppert found that the blood-pressure was not sensibly diminished by lowering the pressure of the atmosphere; a

great reduction in the air-pressure was required to bring about any notable change, and this change must in part be ascribed to phenomena of a chemical order. Hallion and Tissot measured the arterial tension in the femoral artery of the dog; this tension, 15 centimeters of mercury, was the same at 3000 meters as at the level of the ground, although at that height the barometric pressure was only 27 to 28 centimeters of mercury. Like Paul Bert, whose results they almost exactly confirmed, they scout the idea that the expansion of the intestinal gases is capable—especially in man, who has at his command adequate means of defense against this accident—of modifying the tension in the abdominal vessels. On the other hand, the diminution in the pulmonary capacity that results from the forcible elevation of the diaphragm by the expansion of the intestinal gases under a low atmospheric pressure, cannot be disregarded entirely. Some authors explain the peripheral polycythemia previously mentioned by a modification in the volume of the lungs. This hypothesis is hardly in accord with the experiments of Lichtheim, who was able to isolate from the circulation a considerable portion of the vascular apparatus of the lungs without modifying the aortic tension. Lazarus and Schirmunski experimented on sheep in pneumatic cabinets and observed a diminution of the arterial tension.

Effect on the Pulse-rate.—A well-established phenomenon is the acceleration of the contractions of the heart and of the pulse-rate, which takes place very early (P. Bert, Lazarus and Schirmunski). The latter authors also noted dicrotism and diminution of tension in the sphygmographic tracings. According to Loewy, the changes in the circulation depend less on the rarefaction of the air than on the diminution of oxygen.

Effect on the Velocity of the Blood.—It is evident that the velocity of the circulation may, and in fact must, exert considerable influence on the distribution of oxygen to the tissues. An interesting point to determine, therefore, is whether any change takes place in the velocity of the blood when an individual is made to breathe rarefied air. Loewy failed to find any change in this respect so long as the blood supplied oxygen enough to satisfy the wants of the tissues. It is only when the quantity of oxygen becomes insufficient—pressure in itself has no direct bearing on this question—that the rate of the circulation varies. Hüfner, at a pressure of one-half atmosphere, found that the velocity of the blood was increased until the quantity of oxygen brought in contact with the cells of the tissues was sufficient for their needs, so that the saturation of hemoglobin with oxygen was maintained within normal limits. Loewy believes that acceleration in the movement of the blood is a defensive

measure on the part of the organism, and that it is resorted to whenever the expenditure of oxygen becomes excessive and a greater quantity must be absorbed by the tissues.

Effect on the Respiratory Apparatus

The study of the changes that take place in the respiratory apparatus is of the highest importance, for these changes are intimately connected with those resulting in the circulatory apparatus and in the nutrition. The facts revealed by the studies of later investigators necessitate some slight modifications of Paul Bert's conclusions. In general the respiration becomes accelerated as the pressure diminishes, but the diminution of the respiratory rate is extremely irregular, being greatly dependent upon the rapidity with which the air is rarefied. The initial stage of astonishment is quickly succeeded by a period of marked excitement during which the animal struggles violently to escape from its environment; the pressure of the internal gases as they begin to distend the intestine adds to its distress, and all these sensory and motor explosions combine to accelerate the respiration. On the other hand, the breathing not infrequently becomes slower and deeper; in fact, retardation is almost the rule at excessively low pressures, and is observed especially when the animal remains quiet instead of struggling. In all these experiments it appears that acceleration of the respiratory rate is greatly increased by restlessness on the part of the animal. In a word, here, as in all other conditions, diminution of the air-pressure acts in the same way as asphyxia. It is well known that when an animal is asphyxiated in a closed vessel, there is also a period when the respiration is accelerated, followed by one in which the thoracic movements are labored although quite extensive. In addition to the rate, the rhythm of the respiration is also affected; it becomes irregular, often dicrotic, and sometimes very much slower. In dogs subjected to extreme degrees of rarefaction inspiration sometimes appears to consist of two distinct phases: thoracic inspiration, followed by diaphragmatic inspiration. In addition, every general movement is accompanied by a certain degree of breathlessness. These phenomena all agree perfectly with what is observed in man. The maximum respiratory capacity also undergoes diminution. The **vital capacity** was found by Lazarus and Schirmunski to be diminished, although Loewy believes that below 450 millimeters of mercury the volume of the inspired air increases. It is true that the contradiction is only apparent.

Hallion and Tissot made some observations at elevations not exceeding 3500 meters, with the results set forth in the following table:

[illegible]	[illegible]	Absolute Intensity of Interchanges		Relative Intensity of Interchanges	Actual Respiratory Expenditure	Composition of the Expired Air		Apparent Respiratory Expenditure	Respiratory Quotient	Barometric Pressure	Temperature
		CO_2 Exhaled	O Absorbed		Volume of air expired in one minute measured at 0° C. and 760 mm.	CO_2	O	Volume of air expired in one minute at 760 mm. and at the temperature prevailing at the instant when the air leaves the lungs		Millimeters Hg	
[illegible]					Liters	c.c.	c.c.	Liters			
[illegible]	[illegible]	307	337	1.0	9.485	3.24	3.52	10.140	0.92	760	+9° C. (48.2° F.)
[illegible]	[illegible]	349	381	1.1	7.907	4.16	4.81	10.870	0.86	638	+4° C. (39.2° F.)
[illegible]	[illegible]	276	313	0.915	5.787	4.77	5.4	8.000	0.88	546	—0° C. (32° F.)
[illegible]	[illegible]	298	350	1.0	5.675	5.26	6.16	8.600	0.85	493	—2° C. (28.4° F.)
[illegible]	[illegible]	348	367	1.08	10.113	3.24	3.63	10.805	0.89	760	+8° C. (46.4° F.)
[illegible]											
[illegible]	[illegible]	290	311	1.0	8.633	3.36	3.6	9.225	0.93	760	+9° C. (48.2° F.)
[illegible]	[illegible]	260	288	0.91	6.947	3.73	4.13	8.679	0.90	611	+3° C. (37.4° F.)
[illegible]	[illegible]	272	343	1.02	5.680	5.12	6.46	8.740	0.79	490	+2° C. (35.6° F.)

From these observations the following **conclusions** may be deduced: The absolute quantity of air that enters the lungs in one minute, measured at 0° C. and at 760 mm. (actual respiratory expenditure), undergoes considerable diminution as the altitude increases. The changes in the expired air increase as the altitude increases; the proportion of oxygen absorbed and of carbon dioxid eliminated increases as the individual continues to ascend, indicating that the blood constantly takes up about the same absolute quantity of oxygen from the air in a minute; but, owing to the fact that the tension of the oxygen continually diminishes, it was necessary for the blood, in order to maintain the supply required,

to take up a constantly increasing quantity from a given volume of air. The column of the absolute value of the exchanges in the minute—which shows that this intensity is practically the same at every altitude—is a proof of this fact. Thus the equilibrium, which appears to be broken when the true respiratory expenditure alone is examined, is ultimately restored. The absolute value of the respiratory changes is the same at every altitude up to at least 3500 meters; this is a necessary resultant of the two preceding propositions. The apparent respiratory expenditure—that is to say, the amount of air contained in the lungs measured at barometric pressure and at the temperature of the medium in which the subject breathes—undergoes little variation, or shows a tendency to diminish as the altitude increases, in both experiments, but especially in one of them. It is certain, at all events, that it does not increase. The column giving the respiratory quotient shows that this quotient undergoes a variation opposite to what ought to take place if the eliminated carbon dioxid obeyed the laws of the solution of gases. Hence, up to 3500 meters the exhalation of carbon dioxid from the lungs is not influenced by variations in the barometric pressure, and is therefore not subject to the laws governing the solutions of gases (Hallion and Tissot).

According to Loewy, this is what takes place: at first the intestinal gases expand and respiration becomes both more frequent and more superficial; but so soon as the quantity of oxygen in the blood becomes insufficient on account of the constant fall in the barometric pressure, the blood excites the respiratory centers and respiratory movements become deeper. If the barometric pressure falls still lower, the elimination of carbon dioxid increases and the absorption of oxygen diminishes; it is at this time that general disturbances make their appearance, the proportion of oxygen in the blood being inadequate for the demands of organic combustion. According to the theory ingeniously defended by Loewy, a moderate amount of muscular work would be useful by provoking deeper respiratory movements and thus increasing the tension of the oxygen in the pulmonary alveoli. The **tension of the oxygen** is, in fact, of the very highest importance, as Paul Bert has shown in a number of experiments the accuracy of which is above reproach. They have already been referred to, and need not again be repeated; suffice it to say that they absolutely demonstrate the insignificance of the general pressure prevailing in the medium, since, on the one hand, animals breathing in a medium where the pressure is normal, but where the tension of the oxygen is insufficient, manifest similar disturbances and ultimately succumb just like animals subjected to the action of rarefied air. On the other hand, the animal experiences no discomfort whatever when

subjected to a pressure at which such accidents usually take place, providing the tension of the oxygen be adequate. Some of these experiments have been repeated by Loewy, especially those intended to show what occurs when an animal is forced to breathe air that is deficient in oxygen at normal pressure.

The volume of the inspired air increases in direct proportion with the diminution of the oxygen. The depth of the respiratory movements also undergoes a proportionate increase, while the frequency is not affected. The **oxygen tension in the pulmonary alveoli** falls just as the tension of the gas falls in rarefied air. The difference between the tension of the alveolar oxygen and that of the oxygen of the air is at first quite marked, but progressively diminishes because the oxygen furnished by the respiration is more and more perfectly utilized. When the tension of the oxygen in the air contained in the alveoli does not exceed 42 to 45 millimeters of mercury, the blood still absorbs a sufficient quantity of oxygen to maintain the respiratory quotient at its normal figure. It is thus evident that a new factor enters into the problem—namely, the tension of the oxygen, not in the air respired, but within the alveoli themselves. Miescher Rüsch was the first to emphasize this truth; he showed that a diminution of 20 to 30 millimeters of mercury—equivalent to what is observed at numerous elevated stations—is enough to produce during absolutely quiet respiration changes in the tension of the alveolar oxygen amounting to 100 or 101 millimeters of mercury. It must be added that the organism has at its disposal certain protective measures against this diminution in the tension of the gas; consisting chiefly in an automatic increase of the depth of the respiratory movements as the result of the greater stimulation of spino-bulbar centers by the deoxygenated blood. Even a slight deficiency in the quantity of oxygen dissolved in the blood is followed, not perhaps by actual dyspnea, but by an increase in the frequency and depth of the respiratory movements, which, more often than not, escapes observation. Every individual does not possess the same power of influencing the intra-alveolar tension of the oxygen; which explains why different subjects react differently, and even the same subject under different conditions as regards barometric pressure manifests different reactions. According to Loewy, the usual effects, consisting in fatigue and vertigo, make their appearance at a pressure of 397 millimeters of mercury obtained within forty minutes, or of 337 millimeters obtained within thirty minutes; but the effects vary according to the individual. The intra-alveolar tension of the oxygen depends not only on individual factors, but also on the respiratory type of the subject,

on the temperature, the wind, muscular activity, and fatigue. Even at normal pressure fatigue is capable of producing dyspnea; but moderate muscular exercise, by inducing deeper breathing and increasing the quantity of air inspired, may bring about a rise in the intra-alveolar oxygen tension. It must therefore be admitted that the accidents resulting from a sudden diminution of pressure are to be ascribed not to the lowering of the barometric pressure itself, but to the insufficient tension of the oxygen. This was shown by Paul Bert, who, however, dealt with the tension of the oxygen in the surrounding atmosphere, whereas it is the tension in the alveolar air that is important.

Effect on the Digestive Apparatus.—Bert has been criticized for failing to take sufficient account of the effects of diminished pressure on the ear. His observations in regard to it are as follow: at a certain degree of rarefaction the aëronauts experienced nausea, and in the same way animals begin to stagger, shake their heads, with every sign of malaise, and finally vomit; birds almost invariably exhibit the latter symptom. When animals, particularly herbivorous animals, are subjected to extreme degrees of rarefaction, their bodies become extremely bloated by the expansion of the intestinal gases; in some cases the bloating appeared to be great enough to embarrass the respiratory movement. In his own case Bert found this distention of the abdomen distinctly disagreeable, but it was never followed by any serious discomfort provided the clothing was loosened about the waist. The gas escapes in small quantities through the two intestinal orifices.

Effect on Innervation and Locomotion.—Muscular power is rapidly affected by diminution of the barometric pressure; birds refuse to make any effort to fly away, become perfectly immovable, and, as the pressure continues to fall, are unable even to stand up, crouch on the floor of the cage, and finally lie on their side. The same phenomena are experienced by aëronauts; and, in addition to this motor weakness, there is disturbance of sensation, so that they become practically insensible and indifferent. Sensations of special sense, especially hearing and eyesight, as well as moral energy and intellectual activity, also undergo a notable diminution. When the rarefaction is extreme or unduly protracted, death is often preceded by convulsive twitchings, or even true convulsions, which may be very feeble or entirely absent if the pressure has been lowered very gradually. These convulsions are not due to accumulation in the blood of carbon dioxid (Brown-Séquard), which, in fact, diminishes; they represent a violent reaction on the part of the spinal

marrow, which has been overexcited by a sudden change in its nutritive conditions (Paul Bert).

Effect on Metabolism.—It having been established by the experiments of Bert that the effects of lowering the barometric pressure are practically chemical in character, all the phenomena that have been studied are ultimately referred to disturbances of the nutrition, which therefore merit a closer study. At a low barometric pressure an animal consumes in a given time a much smaller quantity of oxygen and produces a much smaller quantity of carbon dioxid than at the normal pressure; this diminution, which is directly proportionate to the diminution of pressure, is clearly manifested at a pressure of $\frac{1}{3}$ of an atmosphere, corresponding to an elevation of more than 300 meters above the level of the sea (Paul Bert). According to Loewy, a clearly defined and constant modification in the respiratory changes is not observed until a pressure of 45 centimeters of mercury, corresponding to about 4000 meters altitude, has been attained. The volume of inspired air increases, the elimination of carbon dioxid is more active; the consumption of oxygen, which is stationary in a resting animal, falls as soon as the animal engages in muscular exercise. But the work performed must be considerable; for a moderate amount of work might even have the effect of causing the disappearance of accidents due to a deficiency of oxygen. The **urinary excretion** is also modified. Paul Bert found a diminution of the urea; while, on the other hand, Fraenkel and Geppert noted an increase in the urinary nitrogen. In some instances Bert observed glycosuria and a diminution of sugar in the liver. The **temperature** is affected by the diminution in the barometric pressure; in balloon-ascension this cause is added to the direct action of the icy air.

Among the **theories** proposed in explanation of the **accidents** that occur in balloon-ascensions—of which, as already stated, that based on the diminution of the oxygen tension seems the most plausible—the following may be mentioned for the sake of completeness: (1) The theory which attributes the accidents to electric modifications. In regard to this Bert remarks that when a man has nothing definite to say there is every probability that he will fall back upon electricity for an explanation. (2) The theories based on an insufficient quantity of oxygen (Humboldt), disregarding the question of the tension of the gas. (3) The theory of cold, which is chiefly defended by Ambard and Fromont de Bouaille. (4) The theories that attribute the accidents to the escape of gases from the blood. (5) The theory of Liebig, who—without altogether

rejecting the influence of the nervous system (since the accidents do not occur at the same altitude in the case of every individual, and even in the same individual do not always occur in subsequent ascensions), or the expansion of the intestinal gases, or the action of the diminished blood-pressure in the brain on the nuclei of the pneumogastric nerve—believes that the principal cause is to be sought in the elastic tension of the pulmonary tissues which increases in power as the pressure of the air falls. (6) The theory of the expansion of the intestinal gases, which, even after the researches of Bert, has been defended recently by Germe, and, much earlier, at the time of the catastrophe of the 'Zenith,' by Colin. The argument, as founded especially on that unfortunate voyage, runs about thus: The causes of death in balloon-ascension are indeed many, especially those which are connected with the diminution in barometric pressure. Some of these causes resulted from the conditions under which the explorers were placed. Two had partaken of food before starting on the voyage, and died; the third had not eaten and survived. The evolution of gas in the digestive apparatus in the first two may have played a considerable part in the production of the fatal asphyxia. It is well known that this evolution of gas is well marked in ruminant animals after they have eaten green fodder, and even at ordinary pressure often produces death from asphyxia by immobilizing the diaphragm. No doubt this evolution of gas is less active in man, but it increases on account of the general malaise and the disturbed digestion, and when the gas begins to expand as the barometric pressure diminishes, the diaphragm is forcibly elevated, its movements become very much restricted and finally altogether abolished. It is known that in climbing high mountains the traveler is at times overcome by a feeling of lassitude, his legs and arms feel absolutely dead; the muscles, bathed by imperfectly oxygenated blood, lose their energy. Now, this fatigue is shared by the diaphragm in common with the other muscles, and it is quite possible that it ultimately becomes completely paralyzed, especially if it is forced upward by the expansion of the intestinal gases. It is quite true that the aëronaut must provide against the cold, and that it is hard to keep warm on an empty stomach; but the meals can be regulated in such a way that digestion is completed before the aëronaut starts on his voyage, after which fermentable food can be replaced by respiratory stimulants and liquid foods calculated to stimulate heat-production. The principal cause of the accidents may be learned by a careful examination of the two victims and of the survivor. It is not an insufficiency of oxygen; for in experiments the animals do not die when the proportion of oxygen is equivalent to that found at an

altitude of 7000 or 8000 meters. The serious accidents, such as hemorrhages in the respiratory passages and disturbances of the circulation, are produced directly by the lowering of atmospheric pressure.

Some of these theories are founded on indisputable facts, such as the effect of cold, or the expansion of the abdominal gases, which cannot be left out of consideration altogether; they do not, however, represent the primary cause, and are not essential to the occurrence of the accidents. The latter are unquestionably due in every instance to the diminution in the tension of the intra-alveolar oxygen. It is on this that the result hinges; all other factors are merely contributory.

But while the exciting cause of a disease may be perfectly well known —while it may be admitted, *e.g.*, that the bacillus of Koch is the cause of tuberculosis and the bacillus of Eberth that of typhoid fever—it does not follow that one is justified in neglecting the factors that affect the growth of the bacilli and enhance or diminish their activities. The same principle applies in this instance. While, therefore, I accept the theory of an insufficient tension in the intra-alveolar oxygen, I nevertheless believe that some of the phenomena which have been attributed to this cause, both in balloon-ascensions and in mountain-climbing, are directly referable to modifications of the **air contained in the middle ear.**

Bonnier has recently made observations on the **effects of balloon-voyages on the ear,** some of which may be cited briefly: The human ear is composed of three fluid media, the external auditory canal, the tympanum, and the labyrinth; these are separated by passive membranes which support an equal pressure on their two surfaces, and any disturbance of this pressure-equilibrium must interfere with their physiologic function. The pressure of the labyrinthine fluid and the pressure of the air in the tympanum must therefore counterbalance the atmospheric pressure and adapt themselves to its variations, and this is accomplished by tympanic or by labyrinthine compensation. **Tympanic compensation** is brought about by the opening of the Eustachian tube that usually occurs during deglutition; but as a higher altitude is reached, the throat becomes dry, the flow of saliva is checked, tympanic compensation is ruptured, and this reacts on the labyrinth. The yawning reflex then intervenes as a last resort to open the Eustachian tube; this yawning frequently occurs in many subjects just before the development of other symptoms of mountain-sickness. **Labyrinthine compensation** is much slower, and is confined within narrow limits; it is accomplished by vasomotor regulation of the caliber of the tortuous and convoluted vessels that line the labyrinthine wall, producing a slight modification in the capacity of the labyrinth and in the tension of its contents. In

his ascension with Jolly, on the 24th of November, 1901, Bonnier, as has been stated, attained in one hour and twenty minutes the altitude of 4500 meters (about 13,500 feet); the barometric pressure being 470 millimeters of mercury and the temperature —4.5° C. (23.9° F.). At 1800 meters (about 6000 feet) the disagreeable sensation of fulness in the ears, or labyrinthine oppression, made its appearance; at about 3000 meters (say 10,000 feet) tinnitus aurium developed, and although at first it could readily be dissipated by ventilating the tympanum, it later became persistent; but eventually disappeared altogether as a result of the compensatory action of the vasomotor innervation of the labyrinth. The concomitant phenomena of pharyngeal oppression with dryness of the throat, respiratory and arterial oppression,—that is, a feeling of vascular fullness and palpitation of the heart,—appeared successively at 300 meters (say 1000 feet), between 3000 and 4000 meters (10,000 and 13,000 feet), and at 4000 meters. At the latter altitude rigidity of the neck and of the trapezius muscle, which is frequently observed in labyrinthine affections, also declared itself. Bonnier's **conclusion,** which cannot be accepted unreservedly for reasons that have just been given, is that the ear is extremely slow to adapt itself to a great variation of altitude, and that aural disturbance is a direct cause of mountain-sickness.

Phenomena Developing during Balloon-ascensions.—The phenomena that develop in succession during balloon-voyages will now be reviewed, the etiology and, whenever possible, the prophylaxis being also given. Up to a certain height, which varies according to the individual, and is never less than from 3500 to 4000 meters (11,000 to 13,000 feet), there is only a slight acceleration of pulse and respiration—compensatory for the diminution in atmospheric oxygen. At the same time, at an altitude of about 2000 meters (6500 feet), the aëronauts experience a certain intellectual exaltation with a feeling of *bien-être*, high spirits, and unusual powers. This exaltation cannot be attributed altogether to the emotional excitement incident to the voyage nor to the greater purity of the air; the increased activity of the circulation brings about a more rapid irrigation of the organs, and particularly of the nervous centers, thus removing the nutritive waste more completely, and by a kind of lavage putting them in a better condition to perform their functions (Bert). Above 5000 meters (16,400 feet) the oxygen of the air diminishes to a point at which its tension in the pulmonary alveoli becomes notably lowered, although it still remains high enough to effect perfect saturation of the blood. The exaltation of the early period subsides; the heart beats rapidly, muscular movements become almost painful, and the cold begins to be felt. At a still greater elevation

bodily rest becomes imperative; the impoverished blood is no longer able to satisfy the demand for increased oxygenation made by muscular contraction, the slightest effort bringing on dyspnea and palpitation of the heart. Strong as he was, Sivel was barely able to lift a bag of sand weighing 20 pounds from the floor of the car. The voyagers are overcome by somnolence; vertigo and tinnitus aurium oppress them, and they become dazed; the sky appears almost black, partly on account of the diminution of the visual power. Finally, at still greater elevations, when in this muscular, sensory, and intellectual apathy to which they are condemned they attempt to make the slightest movement,—raise the arm, like Glaisher or Tissandier,—they suddenly perceive that they have been struck by paralysis without being aware of it, and almost at once the brain, which is no longer supplied with a sufficient quantity of oxygen by the enfeebled heart, ceases to perform its function, consciousness is lost, and unless the balloon is at once lowered, death promptly ensues (Bert).

The accidents may thus be divided into two **periods.** During the first period, when the organism is **struggling** against the environmental change, the tissues, although supplied with blood relatively poor in oxygen, are still able to extract the quantity of oxygen that they absolutely need with little more difficulty than under normal conditions. So long as the altitude does not exceed 4000 or 5000 meters (13,000 to 16,000 feet), barometric pressure being 40 centimeters of mercury, the nutritive and functional disturbances are of secondary importance. If the barometric pressure falls to 37 centimeters (5700 meters—18,700 feet) or 33 centimeters (6600 meters—21,600 feet), the quantity of oxygen contained in the blood diminishes more and more, and at 26 centimeters (8600 meters—approximately 28,000 feet) is less than half the normal quantity. When this point has been reached, the phase of **demoralization** (*phase de déroute*) develops. Grave physiologic disturbances, due to the liberation of an insufficient quantity of vital energy, develop and become more and more intense; the muscles of respiration and the heart, which up to that point had been strained to the utmost to keep up the nutritive changes, become utterly exhausted; the entire muscular system and the nervous system, being barely able to obtain from the blood the amount of oxygen strictly necessary for their static maintenance, are unable to make the slightest effort. And through the usual series of sympathies—the organic harmonies, as they have been called—what had been effect becomes cause; the frozen tissues cannot support the vital combustions; the feeble and slowly beating heart fails to [illegible] forth the nutritive fluid in due abundance; and the unfor-

tunate aëronaut, entangled in this vicious circle, glides rapidly down the hill at whose base death is waiting (Bert).

Prophylaxis.—The occurrence of serious accidents is influenced by certain circumstances which it is absolutely necessary to bear in mind; they are, however, always originally caused by a lowering in the tension of the oxygen contained in the respired air. The first and the most important precaution to be observed before undertaking an ascension to a considerable altitude consists in guarding against this lowering of the tension of the oxygen; and the best means of increasing the tension is to increase the percentage of oxygen in the respired air. Hence, the car of a balloon should always contain a reservoir of hyperoxygenated air (70 per cent.), or even of pure oxygen. By breathing air more and more highly charged with oxygen as the atmospheric pressure diminishes, the tension of the oxygen can be maintained at the same level, or at least can be kept equal to, if not greater than, the tension of the oxygen in normal air. The capacity of the reservoirs must be calculated at the rate of ten liters for each man for each minute spent in the dangerous regions. The reservoirs are made of gold-beaters' skin (prepared ox-gut), and must be filled to only about two-thirds of their capacity, on account of the expansion of oxygen which takes place at great elevations. Bert, in addition, advises that above 5000 to 6000 meters (say 16,000 to 19,500 feet) the air-passages of the aëronaut be directly and permanently placed in communication, by means of a special mouthpiece, with the reservoir of oxygen.

The **time** at which the symptoms appear, and their **intensity,** depend upon a number of circumstances; some connected with the individual, others with the conditions under which the experiment is made. Of **intrinsic conditions** may be mentioned: (1) The quantity of blood in the body, which varies within tolerably wide limits. (2) The respiratory capacity of the blood—that fluid in the normal state containing a variable quantity of oxygen, which depends especially on the individual's peculiarity in the matter of hemoglobin, and, in addition, on the degree of saturation of this hemoglobin. (3) Pulmonary ventilation, which in vigorous and healthy individuals is capable of augmenting the quantity of oxygen in the blood by 300 to 400 per cent. (4) Lessened consumption of oxygen by different tissues of the body, and the state of nutrition of the body. A tissue that has been resting for some time and has accumulated easily oxidizable material differs greatly from a tissue in which these materials have been exhausted by excessive activity; in the first tissue everything is ready for the greatest possible

utilization of the oxygen supplied by the blood, and therefore for the greatest possible production of vital energy; in the second tissue, on the other hand, in addition to the phenomena attending combustion or the liberation of force, the organic equilibrium, pushed to its extreme, requires that the forces of life be economized, and therefore the sum of the possible expenditures in heat and work will be diminished. From this viewpoint, activity of digestion, by throwing into the organism material that is readily oxidizable, must constitute a condition favorable to the preservation of health and strength (Bert). (5) Mental and bodily fatigue. Mental and muscular efforts have a disastrous effect, since they require for their accomplishment a sudden consumption of oxygen, thus encroaching on the already diminished supply of oxygen in the blood which—being needed for the nutrition of the tissues,—the latter are reduced to a state of absolute poverty and impotence. It is therefore important for any one who intends to undertake a balloon-ascension that he be in a good general state of health and that his nutrition be normal. The state of the lungs also has an important bearing, and there is no doubt that individuals afflicted with any disturbance of the breathing, a narrow chest and a tendency to dyspnea, will suffer earlier from the effects of a diminution in the barometric pressure; conversely, individuals who have accustomed themselves by a long series of gymnastic exercises to modify their respiratory type and to increase the depth of the respirations will offer a greater resistance. The tolerance for high altitudes exhibited by certain aëronauts can only be explained on the ground of such intrinsic conditions.

Before starting out it is advisable to take a meal, so as to lay in a store of readily oxidizable material; and to have in the car some strengthening food, so that the aëronauts may eat frequently during the voyage. During the days preceding the ascension all fatiguing muscular, nervous, or intellectual exercises should be avoided. The various articles should be deposited about the car in such a way as to avoid expenditure of muscular effort as much as possible; the ballast-bags, for example, should be so arranged that they can be emptied by cutting a cord and do not need to be raised from the floor to the edge of the car. Comfortable quarters are not only a luxury, they are a direct means of economizing oxygen (Bert).

Unfavorable external circumstances are, in the first place, the cold; and, in the second place, a too rapid ascent. The temperature to which aëronauts are exposed at very great altitudes is quite low, and, as has been shown, numerous authors have attributed the peripheral polycythemia solely to the cold. Since the researches of Lavoisier it is known

that in order to maintain a constant temperature the organism is obliged to consume an enormous quantity of oxygen; hence, since the oxygen of the arterial blood is already diminished, it is readily comprehensible that the cold should hasten the onset of symptoms indicating insufficient oxygenation; assuming, of course, that the limit of possible organic depression has been almost reached—for the organism defends itself as well as it can against the effects of the cold by vasomotor constriction and peripheral polycythemia. Carvallo believes that the action of the noxious products accumulated in the impoverished blood is reinforced by the anesthetic effect of the cold; it is for this reason that aëronauts soon fall into a kind of lethargy characterized by loss of consciousness and a complete absence of general sensation. Another unfavorable circumstance emphasized by Bert is too great rapidity of ascent. Although our ideas in regard to the effects of habit are in a state of confusion, there can be no doubt that modifications of environment have much greater effect when they take place suddenly than when they are brought about more or less gradually. This truth has been abundantly proved in the case of a diminution of barometric pressure. In experiments it has frequently been observed that a diminution of pressure that would strike the animal down at once is tolerated without difficulty when the reduction in pressure is brought on by gradual transitions; while if the animal be not killed on the instant, it recovers and returns more or less completely to its former condition under the same degree of rarefaction to which before it had almost succumbed.

It is therefore important to have plenty of warm clothing in the car, especially furs, and to provide bottles of hot water, or, better, hot air, or some other objects which can be heated before starting and retain their heat for a long time. Various contrivances of this kind, designed especially for the use of automobilists, are to be found on the market. It is also wise to moderate the speed of the ascension as much as possible; unfortunately, however, speed is practically indispensable if it is desired to attain a considerable altitude.

Balloon-ascensions give rise to physiologic phenomena the nature and explanation of which form the subject of many controversies. From a physiologic viewpoint little progress has been made in explaining the effects of a dimunition of barometric pressure. The chief reason for this is found in the physical impossibility of carrying out the delicate observations necessary for experimentation in the car of the balloon after a great altitude has been reached; so soon as a certain limit has

been passed, the aëronaut sinks into a state of apathy that renders him incapable of any mental effort, far less of making accurate scientific observations.

MOUNTAIN-ASCENSIONS

A detailed description of the phenomena observed during the ascent of high mountains is obviously superfluous after the full exposition in the foregoing pages of the effects produced by balloon-ascensions. A very important additional factor, muscular fatigue, enters into the question, the remaining conditions being unaltered. By way of introduction, before attacking the main part of the subject, the following short account of the experiments of Regnard, as given by one who is opposed to the theories defended by that author, will be presented.

A squirrel-cage which can be made to revolve by an electric motor is placed under the receiver of an air-pump with two guinea-pigs, one inside the cage, the other free in the receiver. As the cage revolves the animal is compelled to keep up a continual running and climbing movement. The rate at which the cage revolves is so calculated that the animal has to raise its own weight about 400 meters in an hour. The air is then slowly exhausted from the receiver. So long as the pressure corresponds to an altitude of not more than 3000 meters, both animals remain equally quiet; but as the withdrawal of air continues, the guinea-pig in the cage begins to fall over on its side from time to time, rolls about without attempting to regain its feet, and pants for breath, while the other remains quiet. At 4600 meters it falls on its back, stops moving its legs, and the respiration becomes short and gasping. The other pig continues perfectly comfortable until the pressure indicates an elevation of 8000 meters, when it exhibits the same symptoms as its companion. When the air is turned on again, both animals regain their normal condition, except that the guinea-pig in the cage continues to show signs of illness for several days.*

The influence of the time-factor in balloon-ascensions has been mentioned. In the case of mountain-climbers there are obviously no sudden elevations and the transition from the pressure prevailing at the foot of the mountain to that at the top is much more gradual. But in spite of this favorable condition, accidents are much more common and more serious in mountain-climbing, and are directly due to muscular fatigue, the importance of which has already been pointed out in connection with balloon-ascensions.

* Regnard, quoted by L. Germe.

Historical

The history of mountain-ascensions may be outlined briefly, the reader being referred for full details to the writings of Paul Bert,—who made a complete review of all the narratives up to his time (1874),—to an exceedingly interesting work by Egli Sanclair (1894), and to text-books on climatology. The writers of antiquity, curiously enough, have nowhere left a concise account of the accidents nowadays described under the name of mountain-sickness; although it is evident that abundant opportunities must have been afforded the physicians of ancient Rome for studying these phenomena by the proximity of the Alps and the numerous invasions by Gauls, Cimbrians, and Carthaginians, as well as by the later transalpine campaigns of the Roman legionaries. A number of ascensions of Mount Etna were also made by the ancients.

The first observations on the subject were published during the Spanish conquests in America. These early observers attributed solely to fatigue, cold, and privation the grave accidents that occurred among the soldiers, many of whom fell victims to mountain-sickness. The jesuit Acosta, after many travels through the mountains of South America, first makes a formal mention of the influence of the air at great elevations. He notes the sudden onset of the symptoms, making it almost impossible for him to keep his seat in the saddle; the occurrence, later, of pain, paroxysms of sobbing, and vomiting, first of the contents of the alimentary tract and then of bile and bloody material—symptoms that persisted until he had regained a comparatively low level. Fatigue, vomiting, and diarrhea are common symptoms, and even death may take place. Acosta adds that not only men but animals also are overcome and refuse to go on in spite of the spur. After Acosta may be cited the memoirs of Herrera, of Frezier, of Bouguer, and especially of Don Ulloa, an officer of the Spanish navy charged by his government with the protection of a French expedition sent to Peru in 1736 to measure a degree upon a meridian of longitude. Besides the cold just referred to, those who are not accustomed to these regions are exposed to another inconvenience, which is known as the '*Mareo de la Puna*,' and it is rare for any one to escape. The condition is similar to sea-sickness, being characterized by the same symptoms and following the same course. It begins with dizziness and a feeling of great heat; distressing nausea then comes on, followed by bilious vomiting. The bodily forces are exhausted, prostration ensues, fever is superadded, and the only relief is found in emesis. Some persons exhibit signs of an extreme prostration that would give rise to serious alarm were it not for the certainty that the symptoms are due solely to this '*Mareo*.' It usually lasts one or two days, after

which health is restored completely. The severity of the symptoms varies with individual disposition, but few escape altogether. When a person has once had an attack, it is unusual for him to be seized with it a second time on passing through the 'Puna,' or when coming from the lowlands or any hot region. Another form of disease, to which animals are especially subject, is also observed in these latitudes. Whenever they travel from the plains to the mountain-tops or *punas*, or from the level of human habitations to the surrounding peaks, the breathing becomes so difficult that they ultimately fall and die in their tracks in spite of the frequent stops to allow them to get their wind. The same symptoms sometimes develop on level ground at elevations, so that they cannot be attributed to anything but the rarity of the air; and as the lungs become accustomed to the atmosphere, the feeling of distress disappears. Some difficulty in breathing is always experienced, however, even when going up a very moderate grade, and cannot by any means be avoided—a phenomenon that is not observed in regions where the atmosphere has its normal density. The rarity of the air is beneficial to asthmatic persons when they have contracted their asthma in a denser atmosphere. This form of asthma is known in the region of the Andes under the name of '*ahogos*' or suffocation, and is, in fact, quite common. Those who are attacked by the disease at the lower levels change their abode to higher altitudes, where they can live in comfort, although they do not become entirely cured. Those, on the other hand, who have contracted asthma on the high plateaus feel better in the lowlands, so that a change of air is a certain remedy in this disease. These facts might be taken general advantage of in medicine, and patients might be sent from one region to another, although the same extreme differences of level are not to be found in other countries. Difficulty in breathing is also observed to a certain extent in the elevated regions of the province of Quito, but the effect is less marked. This variation is doubtless due to the fact that these regions lie under the equator or very near it, while the former country is at some distance from the line. It has been concluded from this that the *punas* or mountain-peaks of Peru have a somewhat higher temperature and that the air is milder than in the other countries of South America. It is to be observed, however, that what has been said of Guancavelica is equally true for all the countries extending toward the south. To guard against confusion it should be stated that what are known as '*punas*' in Peru are called '*paramos*' in Quito (Ecuador). [Ulloa.]

In his narrative of an ascension of Chimborazo, Alexander von Hum-

boldt states that he and his companions all experienced malaise, weakness, and a desire to vomit, which, he believed, were unquestionably due quite as much to the lack of oxygen as to the rarity of the atmosphere. He found only 0.20 per cent. of oxygen at that enormous height (6296 meters—20,660 feet).

Since that time innumerable accounts of ascensions of high mountains have appeared, a mere enumeration of which without any details would occupy too much space. Among the more important the following may, however, be mentioned: the report of the scientific commission accompanying the French expedition to Mexico in 1865; the report of the American expedition organized for the purpose of establishing the interoceanic (transcontinental) railroad from the Mississippi to the Pacific Ocean; the celebrated narratives of de Saussure dealing with ascensions of Mont Blanc, Mont Cenis, the Col du Géant, Monte Rosa, and other peaks; the memoirs of Forbes (Col du Géant), of Bravais and Martins (Mont Blanc), of Tyndall, Kolb, Piachaud, Lortet and others. The latter made a careful study of the modifications in the respiration,—with the aid of the anapneumograph of Bergeon and Kastus,—in the circulation, and in the temperature.*

SYMPTOMS OF MOUNTAIN-SICKNESS †

Up to a certain altitude the only symptom observed during ascensions of high mountains is a feeling of **fatigue,** which varies in intensity according to the individual, and in the same individual according to the character of the ascent and the state of the body at the time. The orographic limit for the appearance of mountain-sickness is not invariable, a point that will be referred to again in connection with the conditions that determine the occurrence of mountain-sickness. The very existence of the disease has even been denied; but at present it seems to be generally admitted that at a certain elevation the accidents that will briefly be described never fail altogether and attack animals as well as men.

The **symptoms,** according to Bert, consist at first of an unaccountable feeling of fatigue, hurried respiration rapidly going on to dyspnea, and

* Among more recent works the reader is referred to Chauveau (1866), Kronecker, Payot (1884), Sommerbrodt (1887), Donaldson (1886), Kessner (1887), Capus (high plateaus of Thibet, 1888), von Liebig, Riva-Rocci (1889), Hauer, Janssen and Viault (1890), Gotlatchew, Carillon (1891), White (1892), Egger, Mayorga (1893), Mercier, Infeld, Guglielmincelli, Egli Sainclair, Courvay, Regnard, Prompt (1894), H. Kronecker, LeRoy de Quenet, Rabot, Sellier (1898), Meissier, and Schroeder (1897).

† Synonyms are: veta, puna, mareo, soroche (South America); bis, tunk, dum, mundara, seran, ais (Central Asia); ikak (Borneo); mountain asthma, etc.

violent palpitations of the heart; these are soon followed by a distaste for food, ringing in the ears, respiratory distress, a dazed feeling, vertigo, constantly augmenting weakness, nausea, vomiting, and somnolence; and, finally, by prostration, dimness of vision, hemorrhages from various organs, diarrhea, and loss of consciousness.

In his great work describing his travels in the mountains of Peru, J. J. Tschudi gives the following vivid description of these symptoms as observed in himself: "I was beginning sturdily to ascend the mountain when I became aware of the terrible influence of the rarefaction of the air; as I was walking along I felt a strange uneasiness. I had to keep perfectly still to be able to breathe, and even then I was barely able to get my breath; when I tried to go on, I was seized with an indescribable sense of anxiety and distress. I could hear my heart beating against my ribs; my breathing was short and interrupted; I felt as if there were an enormous weight on my chest. My lips were blue, swollen, and cracked; the capillaries in the conjunctivæ gave way and a few drops of blood exuded. My senses were singularly benumbed: sight, hearing, and the sense of touch were affected; a heavy cloud floated before my eyes, sometimes gray, and often reddish,—I even shed a few blood-stained tears. I felt as if I were hovering between life and death; my head turned; my senses left me and I stretched myself full length on the ground. If unbounded wealth and immortal glory had awaited me a few hundred feet higher up, it would have been a physical and moral impossibility for me even to have stretched out my hand toward them."

Death may occur, and often quite suddenly. Several such cases have been reported from the Andes and the Himalayas.

The individual symptoms, of which we have given a general picture from the writings of Paul Bert, will now be discussed seriatim, the same authority acting as our chief and most trustworthy guide.

Respiration

Both in men and in animals increased frequency of the respirations, with diminished duration, is a constant and early symptom. The respiratory distress rapidly becomes transformed into positive agony; the victim becomes apneic and often experiences actual pain in the thoracic walls. The muscles appear to be contracted and the ribs feel as if they were held in a vise. Rest diminishes but does not entirely dissipate the distress in breathing. There remains a certain degree of dyspnea which comes on after a slight exertion, persists, and continues to increase, showing that it cannot be due to fatigue (Egli Sainclair). The tracings made by Lortet with the anapneumograph of Bergeon

and Kastus show that the amplitude of the respiratory movements is diminished and that the quantity of inspired and expired air is reduced.

Circulation

Acceleration of the pulse occurs before there is the slightest subjective discomfort, and must therefore be specially looked for. The pulse-rate increases in proportion with the altitude, and may reach 120, 130, or 140 beats in the minute. When it reaches this point, distressing and sometimes intolerable symptoms make their appearance: ringing in the ears; pulsation of the carotids and temporals; and sometimes very painful cardiac palpitation.

Hervey, who found that digitalis had no effect on the palpitation, says that he knows of no more alarming or more painful sensation than this exaggerated action of the heart. De Saussure believes that the intensity of the symptoms is proportional to the acceleration of the pulse. Parrot goes so far as to assert that the altitude can be estimated by the frequency of the pulse-beats. During his ascension of Mont Blanc, Lortet counted 64 pulse-beats at 1050 meters; 70 pulse-beats at 1500 meters; 80 at 1605 meters; 108 at 2049 meters; 116 at 3050 meters; 128 at 3932 meters; 136 at 4556 meters; and 172 at 4810 meters, at the top of the mountain.

Character of the Pulse.—The tracings taken by Lortet and by Chauveau demonstrate that the increase in the frequency is not the only modification in the pulse; it becomes progressively smaller, softer, compressible, distinctly dicrotic, and irregular, the arterial tension being greatly diminished. There are some observers, however, who think that the strength of the pulse undergoes but little variation; even Guilbert says that he found it full, strong, and vibrating. **Arterial tension** is generally admitted to be lowered.

The **changes in the venous circulation** are much more conspicuous: the vessels are distended with blood, the skin and mucous membranes of the lips and conjunctivæ congested; the face is purplish, swollen, or bloated. This venous congestion sometimes gives place to a general pallor, especially if the individual continues in the erect posture; it is a sign of approaching syncope, which may go on to complete loss of consciousness.

Among other circulatory disturbances **hemorrhages** must particularly be mentioned, as their frequency has sometimes been greatly exaggerated. The hemorrhages known to occur are the following, in their order of frequency: epistaxis, pulmonary hemorrhage, hemorrhages from the conjunctivæ, the lips, the ears, and the bowels. Epistaxis is very

common in animals. Unusual forms of hemorrhage are hematuria (Martins), metrorrhagia, and premature menstruation (Mademoiselle D'Angeville).

Composition of the Blood

There appears to be no doubt that the blood undergoes some modifications. Clark speaks of the dark color of the blood issuing from the nose of one of his guides. When, a few years ago, an explanation was sought for the fact that in the same ascension some members of the party remained entirely free from mountain-sickness while others were more or less seriously affected, it was held sufficient to attribute the difference to **idiosyncrasy**—a factor that appears to carry conviction in direct proportion to our ignorance of its essential nature. It is now well known that the differences depend on certain complex phenomena referable to a variety of causes, and instead of sheltering our ignorance behind an empty word we can at least attempt to outline in scientific terms the causes that lead to different reactions on the part of different individuals placed in the same conditions. The question has already been discussed at some length in connection with balloon-ascensions, which represent a rapid ascent to a great height without fatigue, and will be referred to again in the interesting study of the effects of a sojourn at great elevations. The present phase of the question represents an intermediate territory. The ascent is not so rapid as in balloon-ascensions; but, on the other hand, it is a question whether its effects are altogether comparable to the effects produced by a sojourn at high altitudes. In other words, the question to be answered is whether the changes in the blood as a whole, presently to be described as resulting from the effects of a sojourn in the mountains, can be brought about in the space of the few hours or days consumed in a mountain-ascension; or whether the organism merely resorts to what I have termed the '*mobilization of urgency*' in the superficial vascular plexuses,—a **peripheral** or **compensatory hypercythemia,** as described in connection with balloon-ascensions. It appears to be an established fact that compensatory hypercythemia takes place quite rapidly and exerts a real influence in mountain-ascensions, although it is probably not true that it is effected at the very outset. The conditions brought about by mountain-climbing are intermediate between the conditions that obtain in balloon-ascensions and those that surround the dweller at very high altitudes. The peripheral, compensatory (or defensive) hypercythemia exhibits a more or less active tendency—depending on the duration of the ascent and its rapidity—to become transformed into a permanent hypercythemia. Any one who has studied the pro-

cesses of hemic repair, as they are observed after the withdrawal of large quantities of blood, and is familiar with the rapidity with which the organism reacts to the insult, will feel no surprise in learning that permanent hypercythemia begins to establish itself within so short a space of time as fifteen to twenty-four hours, being definite enough to make accurate observation of its progress possible. The reader is referred to the discussion of the changes in the blood-cells and in the hemoglobin (pages 141 and 143), and of the means adopted by the organism in accommodating itself to high altitudes (page 138 and pages 180 to 190). According to Mercier, the hematopoietic process during mountain-ascensions consists in the production, within the first twenty-four hours, of an enormous crop of hematoblasts, which explains the increase in the number of colored cells, attaining as much as 600,000 to 800,000 in a day. Mercier asserts that this hypercythemia can be demonstrated positively at the end of eleven hours.

Digestive Apparatus

The digestive disturbances belong to the early symptoms, and rarely fail to appear; they have been compared to the disturbances occurring in sea-sickness, whence the name *mareo*, formerly in common use. They take the form of excessive thirst accompanied by distaste for food—such extreme disgust, in fact, that the sufferers are unable to bear the sight or even the odor of food; nausea; vomiting; and often diarrhea. Gastric intolerance may be absolute; some persons cannot even retain pure water in teaspoonful doses. While the digestive disturbance does not always assume this extreme form, it is rare for the traveler altogether to escape a feeling of thirst and anorexia.

The gastric symptoms have been attributed by many authors to a modification in the secretions—the saliva, gastric juice, bile, and other glandular juices; but no positive proof of this has been furnished. An increase in the secretion of the sudoriferous glands—which can readily be explained by fatigue alone—and a diminution in the quantity of urine have also been observed.

Nervous System

The earliest and most important symptoms of mountain-sickness are connected with innervation. Sudden overpowering **fatigue,** like a blow in the hollow of the knee ('*coup aux genoux*'), renders walking an absolute impossibility even to the sturdiest pedestrian. The fatigue is out of all proportion to the physical exertion, and is not confined to the lower extremities; the lightest load becomes unbearable. Some of the details

narrated by travelers in this respect are as definite as they are picturesque. Gérard states that the arms refuse to perform any kind of work; even speech is fatiguing, according to Hamel; as a result of this loss of muscular power the traveler at last becomes utterly careless of both comfort and danger, as Schlagintweit reports. Egli Sainclair speaks of the great relief of having guides at hand to take off one's boots and gaiters and put one's feet into sabots, as the effort of doing these things would be extremely painful. Headache, sometimes violent and intolerable, is reported by all mountain-climbers; it is followed by various alterations in the sensory sphere, ringing in the ears, diminished sense of taste and smell,* partial loss of hearing, dimness of vision, flashes before the eyes, alternating with opacities. In addition, there is a psychic and intellectual depression, comparable to the muscular loss of power already referred to, making the traveler utterly incapable of any kind of exertion. This prostration finally ends in a profound sleep, from which the sleeper cannot always be easily roused, and which occasionally terminates in death.

CONDITIONS DETERMINING THE ONSET OF MOUNTAIN-SICKNESS

It might be supposed *à priori* that the accidents just described always make their appearance at a certain elevation, and that they increase in gravity in proportion to the altitude; but the facts are quite different. In the first place, mountain-sickness is not an invariable occurrence, at least up to a certain altitude. Many persons, even when they are not accustomed to mountain-climbing, escape altogether. But to deny on the strength of these exceptional instances the existence of mountain-sickness, as a number of modern ascensionists have done, would be equivalent to denying the existence of sea-sickness on the ground that many persons can live through the roughest passage without suffering from the disorder. This skepticism, which is exhibited by a number of Alpine climbers and even by some physiologists, must be mentioned in this discussion, because it is based chiefly on the fact that certain travelers have enjoyed immunity from accidents to which even their guides in some instances succumbed. Miers, Brand, and Strobel accomplished the passage of the Cumbre d'Uspallata in the Andes without discomfort; on Chimborazo, Boussingault and Hall went beyond the level at which von Humboldt and Bompland had been exceedingly unwell; von Humboldt,

* "It was impossible for us to tell whether the soup were good or bad, we had no sense of taste. Red wine tasted like ink, white wine like vinegar" (Egli Sainclair).

von Buch, Elie de Beaumont, and many others since then, have made the ascension of the Peak of Teneriffe without distress, although Riche and Blavier were seized with hemoptysis and forced to stop before they reached the summit. The same observation applies to Mount Etna, where de Forbin and de Sayre suffered great hardships, while Spallanzani and Ferraro were exempt. De Saussure, Beaufoy, Clark and Sherville, Hawes and Fellowes, Bravais, Martins and Lepileur, and others experienced violent mountain-sickness in ascending Mont Blanc; Clissold, Piachaud, A. Tissandier, and many other Alpine climbers, since the ascension of Mont Blanc has become a kind of sport, felt no unusual sensations. The high mountains of Armenia—Elbrouz, Kasbek, and Ararat—have often been visited (Freshfield, Moore and Tacker) without accident; but at a height of 3700 meters (about 12,000 feet) Sudde declared himself exhausted and lay down on the ground. It cannot be argued, in explanation of these differences in the incidence of mountain-sickness, that the external circumstances were not always identical; such an argument is refuted by numerous statements found in the narratives of ascensionists that some members of the party escaped scot-free while others suffered more or less severely from the malady. Ulloa fell exhausted on Pichinka, while La Condamine's breathing was not even affected. Lortet and Durier made an ascension of Mont Blanc on the same day, and the stories of their experiences and sensations are as different as possible. The same individual, making the same ascension, may be ill the first time and escape the effects of mountain-sickness altogether at a later ascension, as in the case of Lepileur, Tyndall, Lortet, and others. Some individuals are extremely susceptible to mountain-sickness,—instance Martin de Moussy, who was attacked by '*puna*' at an altitude of 1970 meters (say 6500 feet),—while others are very refractory. Thus, Jacquement, Durier,—who at the age of sixty made several ascensions of Mont Blanc without the least discomfort,—and Chauveau never suffered from mountain-sickness, although the latter, for all that, does not deny its existence.

Immunity no doubt depends on a variety of causes.* The symptoms collectively known under the name of mountain-sickness are due to

* Forel, in the account of his ascension of Mont Blanc, makes the statement that if the attention is fixed on the phenomena observed with a view to analyzing them, both physical fatigue and moral depression are diminished. On the same principle the traveler does not suffer from mountain-sickness in dangerous portions of the ascent. Javelle makes the same observation, and adds that the monotony of the ascent, the absence of interest or emulation, are predisposing causes, while an interesting conversation or even a mere attentive observation of the landscape will act as a preventive.

a deficiency of oxygen in the blood and in the tissues on account of the diminution in the oxygen tension of the respired air; the deficiency may, however, be neutralized either by **favorable external circumstances** or by a more important factor, namely, the **defensive resources** of the organism itself: hyperglobulia, increase in the percentage of hemoglobin, greater respiratory capacity. These causes will be referred to again and repeatedly; they are mentioned at this point to show that mountain-sickness is not to be regarded as a necessary evil.

The causes that will be dwelt on more particularly are the variations in the respiratory quotient of the blood, and individual inequalities in the development of the thorax. The quantity of oxygen in the same volume of blood may vary widely in different individuals, even in health. Hence the organism probably holds a variable quantity of oxygen in reserve; if this reserve be very small, the need for oxygen is felt much sooner when its proportion, or, to speak more correctly, its tension, in the respired air becomes lowered. The average percentage of hemoglobin in each red blood-cell is extremely variable. Hayem uses the term '*globular value*' (*valeur globulaire*)—color-index—to describe this proportion. In addition, the degree to which the hemoglobin is saturated with oxygen is also subject to variation. It is this difference in the respiratory chemistry of the individual that determines the effect on him of a mountain-ascension. Men with broad chests and a well-developed respiratory apparatus, like the natives of the Andes,—men in whom the respiratory coefficient is high,—necessarily possess a more active pulmonary ventilation. The diffusion of the gases is much better in such persons than in those with narrow chests; and as the absorption of oxygen becomes more active, the escape of the accumulated products of combustion from the blood is hastened. Chauveau, who, as has been said, never experienced mountain-sickness, particularly speaks of his large respiratory capacity, and to it attributes his immunity in great measure.

would be natural to suppose also that habit, training or 'season-
constant residence on the mountains would play an important
production of immunity from mountain-sickness. These
ll be discussed later in connection with the adaptation of the
low barometric pressures. It may be stated at once, how-
nmunity is not the absolute rule among guides, many of
o stop at a certain level and let their travelers go on without
sam[illegible] true of the natives of elevated regions. While
[illegible] Grandidier, and others express surprise at the
[illegible]s, who would run alongside their mules without

experiencing the least discomfort, Humboldt, Caldcleugh, Brand, and Stuebel, on the other hand, saw their guides or '*peons*' overcome by mountain-sickness when they themselves were practically free from discomfort. In the mountains of Central Asia, in Africa, and in Hawaii the natives appear to be quite as susceptible as Europeans; thus, the inhabitants of Koonarvur, of the Peak of Tazigand, and of the Punjaub are reported by various authors to possess no greater resistance than the whites (Gérard, Johnston, Drew). It is only just, however, to add that guides and travelers are somewhat differently circumstanced, especially as regards clothing, food, and the loads they have to carry. Domestic animals are attacked with equal severity. Horses are more susceptible than mules; dogs find great difficulty in running; cats, according to Tschudi, cannot live above 4000 meters (13,000 feet). The latter statement may be corroborated by similar observations at Leadville, Colorado—altitude 10,200 feet (3109 meters). When the mining-camp was established, numerous attempts were made to import some of these animals, but in every instance they died after a short time. Whether a breed of acclimated cats has since been developed or not, R. M. Goepp, who communicates this information, is unable to say. On the other hand, animals whose natural habitat is at a great altitude are rarely affected (Tschudi, Elliston). There can be no doubt that the indigenous tribes gradually become accustomed to the unusual conditions. This adaptation takes place quite rapidly, so that after two or three days, even at the same elevation, the effects of the rarity of the atmosphere become much less marked, as was observed by the brothers Schlagintweit in their voyage on the glaciers of Ibi-Gamin in Thibet. The explanation of these facts, based on the researches of Viault and Müntz, will be given in discussing acclimatization.

The other factors that determine the appearance of mountain-sickness relate either to **external conditions,** such as cold and wind; or to the **individual,** *i. e.*, fatigue, impaired health, rapidity of the ascent, etc.

As in the case of balloon-ascensions, the influence of **cold** is not to be underestimated; it explains why mountain-sickness appears at a lower level on some mountains than on others. Acosta, who was the first author to give an exact description and interpretation of the symptoms of mountain-sickness and the factors determining its onset, distinctly specifies the influence of cold, and especially that of the **icy winds** prevailing at great altitudes. According to Paul Bert, mountain-sickness is practically unknown under a tropical sky below the level of 4500 meters, while in the Alps its occurrence is not rare 1000 meters lower down, the difference being in great measure attributable to the

difference in temperature. The line of perpetual snow approximately corresponds to the earliest appearance of mountain-sickness. The city of Cerro de Pasco is justly dreaded by every traveler on account of its arctic climate, which intensifies the effects of the great elevation. The gigantic mountain-peaks surrounding the city of Quito owe their comparative freedom from the dangers incident to mountain-sickness in part at least to their situation under the equator. At Quito the average temperature is about 14° C. (57.2° F.) (Jameson); the thermometer ranging between 18° and 8° C. (64.4° and 46.4° F.). Lortet's theory is that the great lowering of the body-temperature incident to the enormous expenditure of energy on the part of the ascensionist is responsible for the occurrence of mountain-sickness; but later observers, Forel, Clifford, and Albutt, were unable to demonstrate that such a lowering of the temperature actually takes place. The **wind** is regarded by all mountain-climbers as the source of great discomfort (Lepileur), by some as productive of extreme respiratory embarrassment (Schlagintweit), or even of death (Henderson). Acosta describes the prevailing winds on high mountains as not very violent, but of such penetrating force that men fall dead almost without knowing what is killing them. Finally, it is a well-known fact among guides that certain places on every mountain are particularly dangerous. This is the case with the '*couloir*' (funnel) on Mont Blanc, and in certain places in the Andes. Places where there is some obstacle to the free circulation of air appear to be especially fatal to travelers. It is for this reason that the natives often attribute the occurrence of mountain-sickness to mephitic or otherwise poisonous emanations from the soil or from plants. This theory, which naturally suggests itself in the case of active volcanoes like Mount Etna, is no more worthy of serious consideration than are the numerous other surmises, such as that the active cause is to be sought in antimony in the Andes; in carbon dioxid, in the mountains of China; in a species of moss, in '*la bôôttee*,' in absinthe, in onions, or that mysterious plant, '*dewaïghas*,' so much dreaded by the natives of Kashmir, although they were unable to show it to Cheetham.

The causes relating to the individual have to do chiefly with **diet** and with **fatigue.** Alpine voyagers are unanimous in advising that little food be taken at a time, but that it be taken at frequent intervals, and that nutritious and strengthening articles of diet be selected. Persons with impaired digestions possess little resistance to the disease, and among guides those who lead the most regular lives are most certain to escape.

There remains for consideration the material influence of **fatigue** on

the production of mountain-sickness and on the time of its appearance. The authorities are all agreed that this factor exerts an enormous influence; but while some consider it one of the exciting causes, if not the only true cause of the malady (Bouguer, Dufour), the majority regard it merely in the light of a predisposing factor. Fatigue may bring on mountain-sickness at an altitude at which the disease does not ordinarily occur. Paul Bert was once seriously embarrassed by a run of one kilometer on the somewhat precipitous road of the Great St. Bernard. When the disease has once appeared, the symptoms are greatly accentuated by even moderate exercise in walking or running. One of the best guides in the Oberland twice became temporarily blind as the result of unusual exertion; the traveler Weddel, who until then had been exempt, was overcome by the *soroche* after a rapid run. La Tonanne fell to the ground in a syncopal attack because he suddenly quickened his pace; d'Orbigny, believing himself acclimated, was forced to stop every time he attempted to waltz; Hedringer fell headlong in the snow when he attempted to run to the top of Mont Blanc. A native of the Alps, while attempting to outstrip his companions, rolled over as if he had been shot. Travelers attribute the greater frequency of fatal accidents among horses to their impatience of the spur, while the mules, patient and obstinate, survive because they refuse to increase their speed. It is in going up the mountain that fatigue and exhaustion are most marked. The fatal influence of muscular activity is felt at every degree of elevation; but at a moderate height its effects are dissipated by rest. This is the most characteristic feature of mountain-sickness. So soon as the traveler lies down, or even sits down, his extreme fatigue and deadly anxiety are suddenly replaced by an unexpected feeling of *bien-être;* the rhythm of the heart is restored; the respiration becomes regular, his strength is revived as if by magic. After a few minutes the inexperienced traveler, astonished at his sudden recovery no less than at the unaccustomed malaise, resumes his upward journey only to be again overcome by the invisible foe. On the highest mountains rest, even in the horizontal position, does not quite restore the sufferer to his usual calm, although the most violent symptoms are relieved. Sleep is prevented or at least disturbed by palpitations and a feeling of impending asphyxia. Sometimes during the night, and especially toward sunrise, the sleeper is awakened by sudden respiratory distress, which is relieved by a few deep inspirations. This is probably an instance of 'forgetting to breathe,' as de Saussure puts it: the sleeper is suddenly awakened by impending asphyxia (Paul Bert). The fatigue incident to the necessary labors of camping, as distinguished from the fatigue of the ascension proper, insomnia, broken rest, and

general discomfort, are also important factors in bringing on the disorder. Those who make the ascension of Mont Blanc in one day are more often attacked than those who break the journey and take a night's rest at the Grands Mulets, as in Lortet's case.

Mountain-sickness and Fatigue.—While it is undeniable that many of the symptoms of mountain-sickness closely resemble the effects of fatigue, their sudden onset and their persistence during rest, or in some cases even after a night of sleep, prove that they are essentially different. Accordingly a number of theories, based on a different conception of the phenomena, without, however, excluding the influence of fatigue, have been advanced by various authors. Dufour sees no resemblance between the accidents that occur during balloon-ascensions and those observed in mountain-climbing. He regards the excessive muscular exertion as the sole cause, and states that he was able to induce all the symptoms of mountain-sickness, including the nausea, by walking up out of the mines at Freiberg for three hours without taking any food. The excessive muscular exertion speedily burns up the ternary matters available in the muscles and in the blood, and the time comes when the ascensionist, if he does not eat, no longer possesses a sufficient quantity of available combustible material and is unable completely to make up the deficit by absorption. This excessive consumption of ternary substances is undeniable, but, except as regards its intensity, is not peculiar to great altitudes. The excessive consumption referred to by Dufour occurs in the same degree during any ascent, whether it takes place below 1000 or above 4000 meters; but the secondary phenomena are quite different (Paul Bert). Lortet and Marcet express the belief that the excess of mechanical work demanded by the ascension is made at the expense of the heat developed by organic oxidation processes, resulting in a lowering of the body-temperature, which, they say, is the cause of the symptoms. But there is a want of agreement as to the nature and extent of the variations of temperature, and especially as to their significance in this theory. Gavarret's theory that mountain-sickness is due to an excessive production of carbon dioxid and consequent poisoning by the gas represents another alluring variation of the fatigue theory. There is no doubt that an excess of carbon dioxid is actually produced as a result of the mechanical work performed during an ascension. According to the views cited, if the ascension be performed rapidly, the respiratory elimination, although much increased, is still inadequate for the maintenance of the normal composition of the blood, which becomes saturated with carbon dioxid; breathing is greatly embarrassed, dyspnea becomes extreme and accompanied by headache, vertigo, and somnolence. It is readily understood

that a rest of a few minutes is enough to cause all these symptoms to disappear. It has, however, never been proved that the excess of carbon dioxid is stored up in the blood. The gas is rapidly eliminated by the action of the lungs, and it seems questionable whether it accumulates in the blood of ascensionists in sufficient quantity to produce toxic symptoms. Even granting that such were the case, the symptoms of mountain-sickness do not show a close resemblance to those of carbon-dioxid poisoning, and, finally, Bert points out that these symptoms would then appear at any altitude, and therefore have nothing in common with mountain-sickness. The object of relating the experiments of Regnard (see p. 162) was to emphasize the influence of fatigue in the production of mountain-sickness, but it is impossible to accept it as the direct or indirect cause of the disease. It is to the influence of fatigue that we must ascribe the fact that mountain-sickness appears at a much lower altitude than does balloon-sickness; and to the same cause, in a sense, must be attributed the appearance of mountain-sickness at such different levels. This phenomenon, which is due to a variety of causes, has long been known; the steeper the ascent, the more frequent are the accidents; and although the ascent of a mountain by a gentle slope may not be attended with the smallest discomfort, difficulties at once arise if a more abrupt route is selected. If the line of ascent is practically vertical, the body has less time to become habituated to the change of pressure than when the ascent is made by stages and interrupted by a halt at various altitudes (Carvallo). As will be shown when discussing the effects of sojourn at altitudes, the organism is endowed with a certain power of adaptability which explains the much later onset of mountain-sickness on the lofty peaks of the Himalayas and of the equatorial Andes.

Onset According to Geographic Distribution.—Mountain-sickness appears at different levels in the various mountain-systems of the globe. In the Pyrenees the disease is always mild, and rarely or never occurs below 3000 meters (say 10,000 feet). In the Alps it is quite frequent above from 3000 to 4000 meters (13,000 feet), and practically constant above that level. In the Caucasus and on Mount Ararat the limit appears to be somewhat higher. On the volcanoes of the Pacific, which are more than 4000 meters in height, and on the Cameronian Mountains no more discomfort is felt than on the Peak of Teneriffe. On the Kilimandjaro, New climbed to a height of 5000 meters without serious inconvenience. In North America, Fremont and his companions were ill at 3500 meters (say 11,500 feet); but in Mexico pronounced symptoms are not felt below an altitude of 4500 meters (say 14,500 feet), and even at the top of Popocatepetl, 5420 meters (17,780 feet), they

are not always very serious. It is impossible to cross the long range of mountains in South America at any point between Chile and Colombia without being attacked by the terrible *puna;* but even here the accidents are not observed at the same level everywhere: in the passes of Santiago de Chile many are overcome at an altitude of less than 4000 meters; almost every foreigner is attacked by the disease at La Paz, 3720 meters (12,200 feet), and even at Chuquisaca, 2845 meters (9334 feet); and all without exception at Cerro de Pasco, 4350 meters (14,270 feet); while the mountains surrounding Quito are practically safe up to a height of 5000 meters (say 16,500 feet), and a thousand meters higher up present no insurmountable difficulties. The gigantic mountains of Central Asia may be compared to the Andes of Upper Peru as regards the level at which mountain-sickness makes its appearance. Passes of less than 4500 meters' elevation may be crossed without serious inconvenience; some that exceed 5500 meters (say 18,000 feet) are quite frequently visited; while a number of travelers have attained the height of 6000 meters (say 19,500 feet). The brothers Schlagintweit climbed to the prodigious height of 6882 meters (22,580 feet) on the slopes of the Ibi-Gamin.

Relation between Altitude and Intensity of the Symptoms.—Although the intensity of the symptoms, generally speaking, increases with the altitude, there is not a constant proportion. It is obvious that the ascension of a mountain situated near the sea must be attended with a much more sudden change of pressure than that experienced when the base of the mountain is reached by successive stages, as in the case of the Alps when approached from the French or northern slope, where the level at which the actual ascent begins is already about 1000 meters (3281 feet) above sea-level.

Influence of Temperature.—In addition to the sudden change of pressure, and the muscular exertion incident to the ascent, the **temperature** must be mentioned as an important factor. Although it is impossible to establish a fixed law, it appears from a comparison of the narratives of various travelers that the appearance of mountain-sickness bears a certain relation to the line of perpetual snow; in other words, to the temperature. Some observers have even considered the relation as one of cause and effect, whereas the temperature is only a predisposing factor. In the Alps the earliest unmistakable symptoms appear at a level of 500 meters (1640 feet) or less above the line of perpetual snow. In the Himalaya Mountains and in the Bolivian Andes mountain-sickness prevails at an altitude much below that of perpetual snow; while on the volcanoes in the equatorial regions, in the Mexican Andes, and on the

Rocky Mountains the limit is about the same as in the Alps, counting from the snow-line.

Conclusion.—That mountain-sickness is an actual disease can no longer be doubted. Among the numerous theories proposed for its explanation, which have not as yet been mentioned in this chapter, and have now practically been abandoned, Cunningham's theory of electrical modifications; the theories based on the diminution of the weight supported by the body, and those based on the expansion of the intestinal gases may briefly be referred to.* There are others besides which need not be mentioned. In addition to the contributory causes, the influence of which has been discussed at length, the symptoms of mountain-sickness must be attributed chiefly to the deficiency of oxygen in the blood and in the tissues. Humboldt, and later Boussingault, sought the cause in the poverty of the air at great elevations; de Saussure and Martins went further, and invoked the diminished density of the atmosphere, supplemented by the increased frequency of the respirations. De Saussure's theory found numerous adherents; but Pravaz soon showed that the proportion of oxygen in the air, even at the summit of the highest mountains that have ever been ascended, is sufficient to meet all the demands of respiration and to make up for the increased combustion incident to the exertion of the ascent. Pravaz, without offering proofs, attributes the accidents to the absence of pressure and consequent diminished solution of oxygen in the blood. Jourdanet, who boldly mentions anoxyhemia as the cause of mountain-sickness, asserts that an ascension above 3000 meters is equivalent to barometric deoxygenation of the blood, just as venesection is a globular deoxygenation. But we are indebted to the persevering labors of Paul Bert for our precise knowledge that the primary cause of mountain-sickness is the **diminished tension of the oxygen** in mountainous regions, resulting in deficient oxygenation of the blood and of the tissues. Bert's researches have been confirmed by Egli Sainclair, who showed by repeated and accurate examinations of the hemoglobin that the latter undergoes a material diminution during mountain-ascensions, especially in those who are attacked by the disease.

The prophylactic measures to be employed need not detain us, as they are readily deduced from the foregoing detailed description of the symptoms.

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* Acute meteorism (bloating) in ruminants presents some striking resemblances to mountain-sickness (L. Germe).

Therapy

Mountain-ascensions have not, so far as I know, been utilized for therapeutic purposes, and it is therefore unnecessary to devote a special section to this aspect of the subject, as the deductions that could be offered would be purely theoretic. It is my firm belief that the ascension itself might frequently be utilized; but I have no observations at my command wherewith to support such an opinion. The results obtained by a sojourn in mountainous regions, according to the common custom, have nothing in common with the effects of mountain-ascensions.

ADAPTATION OF THE ORGANISM TO HIGH ALTITUDES

Experience teaches that a sudden, marked change in the atmospheric pressure is productive of grave disturbances that may even culminate in death. Nevertheless it is well known that human inhabitants are found in South America, in Central America, and in the Himalayas at so great an altitude as 4500 meters (14,760 feet); and it must therefore be assumed that the organism possesses the power of adapting itself to the conditions present in regions characterized by a high degree of atmospheric rarefaction. The words 'custom' and 'habituation' that are so glibly used merely serve to indicate the fact without explaining it.

Paul Bert's classification of the phenomena according to whether the altitude exceeds 2000 meters (6560 feet) or falls below that limit lacks scientific foundation, although it appears to be supported by the researches of Zuntz and his disciples. The process of adaptation takes place at any altitude. The increase in the power of the blood to absorb oxygen, which Bert first enunciated as an hypothesis and later was able to verify, is attributed by him chiefly to a diminution in the intensity of respiratory combustion. He believes that under normal conditions of pressure we consume much more oxygen than we need, just as we habitually eat more than is necessary. Thus, the native mountaineer who sustains his strength with a piece of bread and a few onions, while the member of the Alpine Club on the same ascension requires a pound of meat, is probably able to cut down his consumption of oxygen without suffering any loss either of body-temperature or of power to perform work. This Bert regards as the explanation of the phenomenon of acclimatization of individuals, generations, and races. In addition to the changes in the nutritive processes themselves, it is probable that a modification in the excitation of muscles, nerves, and nerve-centers is brought about by a reduction in the quantity of oxygen absorbed by the

blood. While it is impossible to ascertain by mensuration the precise degree of excitation, it is not unreasonable to suppose that these delicate organs are differently affected by the arterial blood when it contains only 16 instead of 20 volumes of oxygen, quite apart from the question of oxidation processes as such; and it is at least probable that under the latter conditions their average activity is diminished. In spite of this, however, he concludes with Jourdanet that those who live at great elevations, even the native Europeans, are almost regularly anemic, notwithstanding their appearance of health, and that this tendency to anemia manifests itself especially in the presence of any disease that interferes with the absorption of oxygen. This assertion Bert qualifies with the admission that he does not feel the same confidence in his clinical acumen as he does in his judgment of laboratory questions, and therein displays the scientific quality of his mind; for it is a well-known fact that the Indians inhabiting the high mountain-peaks of the Andes (Roy) and the Quichuas are a hardy and vigorous race, square-shouldered, with broad, capacious, and very long chests, indicating large pulmonary capacity. The inhabitants of the high plateaus of Thibet combine the physical vigor of the Tartar with the suppleness of the Chinese, and have earned the appellation of 'cod,' which in their language signifies strength.

Jourdanet's theoretic anemia is therefore a myth; and the adaptation of the organism to low barometric pressures an indisputable fact. The process of adaptation is even quite rapid, as was shown during the ill-fated Austro-French expedition to Mexico in 1863, when it was observed that the troops stationed on the high plateaus of Anahuai became easily and completely acclimated (Coindet). The most important changes affect the blood, but all the other systems of the body, including especially the nervous system, also play their part in the process of acclimatization. Much remains to be investigated, and we are far from possessing definite knowledge of all the phenomena; some facts have, however, been ascertained and should be enumerated, bearing in mind that they relate rather to the stage of adaptation than to the period of complete acclimatization.

Respiration.—One of the most constant phenomena is the change in the type of the respiration, which is increased in frequency as well as in depth (Jaccoud, Vacher). The therapeutic effect of this change is that the upper portions of the organs, which under ordinary circumstances take a very feeble part in the respiratory expansion, are brought into action. According to Armieux, the increase in the capacity of the thorax is considerable, the average increase in the circumference being 2 or 3

centimeters—$\frac{3}{4}$ to $1\frac{1}{4}$ inches. As a result, a greater quantity of air enters the lungs in a given time and is distributed to better advantage in the bronchial tree. Gréhant has shown that while the coefficient of ventilation is 0.060 for an inspiration of 300 cubic centimeters, it is increased to 0.159 for an inspiration of 600 cubic centimeters; that is to say, it is much more than doubled when the inspirations are doubled. Eighteen inspirations of 500 cubic centimeters in the minute (9 liters) renew the gases in the lungs more effectually than would thirty-six inspirations of 300 cubic centimeters (10.8 liters). Coindet found that recent arrivals on the high Mexican plateaus inspired 5.47 liters in the minute, while those who were acclimated inspired 6.32. Schumberg and Zuntz studied the respiratory interchanges at various elevations ranging from 42 to 3800 meters (138 to 12,464 feet) in the resting and in the working state. During repose there is a moderate increase in the absorption of oxygen and elimination of carbon dioxid, proportional to the increase in altitude, and which can be augmented still further by voluntary increase in the depth of the breathing. During the performance of the same quantity of work the increase in the consumption of oxygen is greater by 33 per cent. at high elevations than on the plains. It would appear from the studies by A. and J. Loewy and Müntz on respiratory interchanges and the mechanism of respiration in the pneumatic chamber and on Monte Rosa, that the conditions are not quite identical in the two media. The changes observed in the pneumatic chamber are comparatively insignificant, while on the mountains the respiratory interchanges are distinctly augmented. Loewy and Zuntz found that the initial acceleration of the pulse and of the respiration disappeared at the end of twelve days. It appears, therefore, that the perfect tolerance of low barometric pressures exhibited by those who are acclimated is not to be ascribed to the sudden changes that characterize the period of adaptation.

Metabolism.—The results reported by different investigators are rather contradictory; in general, an improvement in the appetite and an increase in the excretion of urea and urinary salts have been observed to follow a change of residence to moderate elevations. Terray asserts that an increase of from 8.7 to 10.5 per cent. in the proportion of oxygen in the respired air is not productive of any material change; when, however, the proportion of oxygen falls below 10.5 per cent., an increase in the elimination of carbon dioxid, nitrogen, and lactic acid is observed. He also found that the elimination of oxalic acid was increased in the dog.

Effect on the Blood.—At first Paul Bert believed that the principal factor in the adaptation of the organism was to be found in a diminution

of the superfluous loss of oxygen to which the body is constantly subject. In 1882 he received from La Paz specimens of blood taken from perfectly acclimated and healthy men and animals, which he found was capable of fixing a much greater quantity of oxygen than the blood of men and animals living on the plains. Since it has been shown by the investigations of Jolyet that hemoglobin, when brought in contact with the air, takes up a constant quantity of oxygen, and that the latter is not affected by the time at which the blood is taken from the body, he concluded that in men and animals living at high altitudes the respiratory capacity of the blood, and therefore the quantity of hemoglobin, is augmented. This increase in the hemoglobin represents the organism's means of defense against the anoxyemia which threatens its integrity at an elevation greater than 2000 meters—6500 feet.

Viault passed in review all the possible factors in the adaptation of the organism, such as acceleration of the pulse and respiration; increase of the hemoglobin; diminished need of oxygen on the part of the tissues; and diminution of the process of organic combustion. He was the first to discover a considerable increase in the number of erythrocytes in the blood of those who inhabit the high plateaus of South America. An individual possessing normally 5,000,000 erythrocytes in a cubic millimeter of blood presents 7,000,000 after two weeks' sojourn, and 8,000,000 at the end of three weeks. In a young dog the number of erythrocytes was found to be 9,000,000; the normal count in the llama is 16,000,000. He also found this increase in the blood of animals which he first examined on the plains and then transported to the mountains. On the other hand, Viault observed no change in the percentage of hemoglobin either during his researches in the Cordilleras of Peru, where the altitude is 4392 meters (14,405 feet), or in his later expeditions to the Pic du Midi. He believes that the hypercythemia that he observed accurately neutralizes the effects of the rarefaction of the air, or, in other words, of the diminution in the tension of the oxygen. Another interesting discovery made by Viault is that while he found numerous microcytes in the blood of men and animals recently arrived on the high plateaus, the colored cells were all normal in size, once acclimatization had been established.

Müntz found that the blood of rabbits that had been living on the Pic du Midi for seven years contained twice as much iron as the blood of rabbits living on the plains, and possessed a greater power of absorbing oxygen. In the case of sheep similar modifications were observed after six weeks. At Reiboldsgrün, with an altitude of only 700 meters (2296 feet), Wolff and Koeppe noted a rapid and marked increase in the num-

ber of erythrocytes. Egger found that on Mount Arosa, with an altitude of 1890 meters (6199 feet), the increase in the number of erythrocytes at the end of two weeks was, on the average, 16.6 per cent. Natives of Mount Arosa, and those who had lived there for years, presented a red blood-cell count of 6,000,000 to 7,000,000 in the cubic millimeter and a marked increase of hemoglobin; in those who had recently become acclimated lower figures were obtained, showing that acclimatization is still incomplete at the end of a month. Like the majority of other observers, Egger found that the hypercythemia rapidly diminished after the individual returned to the plains. Karcher, Suter, and Veillon arrived at similar conclusions at elevations respectively of 1052 meters (3450 feet), 985 meters (3230 feet), and 700 meters (2296 feet). It is to be noted, however, that a difference of 434 meters (1424 feet) between Basel, 266 meters (872 feet), and Langenbrück, 700 meters (2296 feet), produces only a slight increase in the number of erythrocytes and in the hemoglobin. This has an important bearing on the therapeutic utilization of mountain climates. The facts cited are further confirmed by the researches of Mercier, von Joruntowsky, and Schröder.

Hypercythemia, then, is an established fact; it is produced very rapidly, as a rule attaining its maximum in three weeks; when the individual returns to a lower level, the number of erythrocytes in a short time returns approximately to the figure obtaining before the sojourn in the mountains, provided it was then normal. Those previously anemic, however, may retain sufficient of the increased erythrocytosis of altitude to restore them permanently to a normal state.

Most authorities are agreed that the hypercythemia is due to a true new formation of red blood-cells; other explanations have, however, been offered, especially for the rapid production of hypercythemia sometimes observed within a few days or even hours.

1. According to one theory, it is due to **concentration of the blood** as a result of the extreme dryness of the air at high altitudes. Sahli and Limbeck thought this factor worthy of consideration; but Egger, after weighing the dried blood-serum of two guinea-pigs, one of which had been left at the foot of the mountain while the other lived for three weeks at the summit of Mount Arosa, at an altitude of 1800 meters (5904 feet), had little to say in favor of the theory. Grawitz is the most outspoken and emphatic supporter of the theory of concentration. His arguments, which will be given briefly, are based chiefly on the rapid production of hypercythemia observed in the case of ascensionists, which, it is quite true, is susceptible of a special explanation; but he has erroneously

applied his conclusions to the permanent hypercythemia that occurs at high altitudes. He calls attention to the fact that an increase of one million red blood-cells in the cubic millimeter of blood, occurring within the space of twenty-four to thirty-six hours, during an ascension to a moderate height such as Reiboldsgrün, is equivalent to an increase of five billions in the total quantity of blood. Even admitting the presence of a large number of microcytes, this would imply a considerable increase in the percentage of hemoglobin, the occurrence of which has been denied—some observers having even found an initial decrease. This change in the condition of the blood is not accompanied by any manifestations of plethora, and, what is even more inexplicable—since the phenomenon is more marked in sick persons than in those who are well—is not followed by any constitutional reaction whatever. Finally, it has been determined by repeated blood-examinations that rapid regeneration of the blood is accompanied by certain specific changes in the cells, especially by the appearance of nucleated red blood-cells, the presence of which under these conditions has not been reported by a single observer.* In most of the known cases of hypercythemia, also, there is a certain degree of leucocytosis which is absent in the rapid hypercythemia occurring at high altitudes. Grawitz also calls attention to the extreme rapidity of the production of this hypercythemia, which is at variance with clinical experience under other conditions.

With the exception of Schaumann and Rosengrist, all observers are agreed that the hypercythemia disappears rapidly in both men and animals, so soon as they return to the level, without producing the slightest discomfort or any of the symptoms observed after conditions attended with the wholesale destruction of red blood-cells—such as jaundice and hemoglobinuria (Ponfick, Naunyn, Stadelmann, Hayem and Eissier).

Grawitz also refers to Marestang's observations that a marked increase in the red cells takes place in the blood of sailors after they have lived a certain length of time in tropical zones, without undergoing any change of altitude; the increase amounted to about one million. The phenomenon is explained by the increased loss of water from the tissues,

* Grawitz refuses to see any significance in the appearance of numerous small cells,—young erythrocytes, according to Hayem,—on the ground that the size of the cells varies in different individuals, and can also be made to vary at will, as by fasting, the administration of morphin, hot applications to the periphery, and by inducing fever. It would not be difficult to show that these arguments do not disprove the hematoblastic theory; and, on the other hand, the occurrence of nucleated red cells has been reported by Gaule, although it is true that he is the only observer who found them.

not by an increase in the number of erythrocytes in response to the need of absorbing a greater quantity of oxygen.

To this loss of moisture from the tissues of the body Grawitz also attributes the dryness of the skin and of the mucous membranes; the increased thirst, without corresponding increase in the quantity of urine; the cutaneous eruptions; the cracking of the lips that is frequently experienced in the mountains; and the subsidence of night-sweats in phthisical patients. He performed a number of experiments to support his theory of concentration of the blood, which he regards as proved; nevertheless he found only a slight increase in the dry residue of the serum, and that only after several days. He believes that the erythrocytes themselves suffer a loss of water, and that this explains the increased number of microcytes.

Schaumann and Rosengrist repeated the experiments of Grawitz, taking the additional precaution to maintain the proportion of aqueous vapor at or above the level of the proportion in the atmosphere, so that a loss of moisture was out of the question. They found that hypercythemia was nevertheless produced.

These experiments therefore completely upset the conclusions of Grawitz, against which also a serious objection was raised by Zuntz, when they were reported by their author to the Berliner Medicinische Gesellschaft. Admitting the correctness of Grawitz's view, he says, an increase of five to six millions in the number of erythrocytes contained in a cubic millimeter of blood necessarily implies that the blood has lost one-fifth of its water; and if the total quantity of blood is estimated at five liters, there would remain only four liters. But in that case the entire organism would also lose a considerable quantity of water, for there is a constant osmotic interchange between the blood and the tissues, and any loss of water in the blood must make itself equally felt in the tissues. By a simple calculation it is found that a loss of one liter of water from the blood is equivalent to a loss of 7 or 8 kilograms—15.4 to 17.6 pounds—in the weight of the body. But no such loss of weight is revealed by the scales. Grawitz objected that he referred principally to the loss of water from the erythrocytes, and that this would explain the large number of microcytes, but that is evidently no answer to Zuntz's arguments. Even if the dry residue of serum were found to be increased in weight, it would not be an argument in favor of the theory of concentration of the blood; for von Hönlin has shown that during the period of regeneration succeeding venesection, the weight of the residue or of the serum increases. I have purposely devoted much attention to the important and often quoted work of Grawitz; but I cannot accept his

conclusions, although they unquestionably contain a modicum of truth. It is impossible to believe that such great production and destruction of red blood-cells can take place within the space of a few hours, and I have already proposed quite a different explanation in the section on balloon-ascensions. Where Grawitz is wrong is in refusing to take account of the permanent hypercythemia that is produced in those who have become acclimated.

Egger, whose work has already been referred to, observed the greatest increase in the number of the erythrocytes, from 26 to 48 per cent., in the case of **anemic patients;** but it does not occur in every case, some anemic individuals showing the lowest figures in his series. After from three to four and one-half weeks the increase, in the case of guinea-pigs, amounted to from 14 to 33 per cent., although there was no appreciable change in the weight of the dry residue of the centrifugated serum, which tends to disprove the hypothesis of Grawitz. Egger believes that the hypercythemia is the result of increased stimulation of hematopoiesis, which, in turn, is due to the diminution in the tension of the oxygen.

2. **Increase in the vital resistance of the erythrocytes, with less rapid destruction of these elements.** This theory was promulgated and defended by A. Fick, who, however, failed to demonstrate its truth. It is evident that the ultimate result is the same whether we assume a new formation of erythrocytes or an increase in their length of life. To elucidate the question, Fick suggests measuring the daily quantity of bile secreted by the same animal on the plain and at the top of the mountain, as the hemoglobin liberated by the physiologic or pathologic destruction of the red blood-cells, when it does not exceed a certain limit, is taken up by the liver and eliminated in the form of bilirubin.

3. **Modification in the distribution of the erythrocytes in the blood.** This theory, which naturally suggests itself for the explanation of the rapid peripheral hypercythemia observed in aëronauts and ascensionists, has also been invoked to explain the condition under discussion. Zuntz first raised the questions whether a certain portion of the plasma passes from the blood-vascular to the lymphatic system, and whether any change takes place in the respective proportions of plasma and of erythrocytes at certain points in the body, as the investigations of Cohnheim and Zuntz seem to show. The latter observed marked variations depending on the degree of contraction of the arterioles: in the capillary system large spaces contained almost nothing but plasma, while under different conditions the same spaces were found literally packed with red blood-cells. E. Meissen and Schröder observed an increase in the number of erythrocytes in the blood of healthy persons as well as of tuberculous

subjects at Hohenhonnef am Rhein (altitude 236 meters—774 feet); but they are inclined to doubt that the increase observed in the capillary network exists also in the veins and arteries, and in the end adopt the opinion of Zuntz. Schumberg and Zuntz lay stress upon the special influences to which the nervous system is subjected at great altitudes. The increase in **solar radiation** must be considered one of the chief factors in the modification of the nervous system. The latter affects the caliber and tension of the vessels and thus brings about an increase in the number of the red blood-cells in the peripheral vessels.

It is to be noted also that the results obtained by Schumberg and Zuntz in regard to the increase in the number of erythrocytes are quite different from those of other observers. They found that it was smaller on the heights than on the plain; the specific gravity of the blood, which depends almost exclusively on the number of erythrocytes, and the specific gravity of the serum were constant. To explain the discrepancy Schumberg and Zuntz assume that the moderate stimulation produced by a comparatively moderate elevation, not exceeding that of Mount Arosa (1800 meters—5904 feet), contracts the lumen of the arterioles and leads to an increase in the number of erythrocytes in the peripheral vessels, while the extreme stimulation produced by great altitudes, as a sudden rise from 400 to 5000 meters,—say from 1300 feet to 16,000 feet, —within forty-eight hours, produces a dilatation of the arterioles and a decrease in the number of erythrocytes.

On the other hand, the hypercythemia is not absolutely proportional to the altitude, and the accompanying graphic representation of the blood-curve (Fig. 17), taken from Fromont de Bouaille, shows that while it is quite marked at low altitudes, it subsequently undergoes a relatively slight increase.

4. **Increased hematopoiesis.** This is the theory adopted by the majority, although it should be stated at once that it has not been absolutely proved. Owing to the diminution in the tension of the oxygen, the degree of saturation of the hemoglobin is diminished, and to compensate for this deficiency the organism reacts by a stimulation of the hematopoietic organs, rapidly resulting in hypercythemia. The process is analogous to the phenomena observed whenever the oxygenation of the blood is impeded, as in malformations of the heart or in cyanosis. A variety of arguments have been advanced by the supporters of the theory; some of these refer to general physiology, as, the necessity on the part of the organism to react in the presence of a deficiency of oxygen; others exhibit a more specialized character, as—

(*a*) The increase in the number of erythrocytes does not attain its

maximum at once. At first it is quite rapid, but soon its activity diminishes, being still present, however, at the end of several weeks or months, although never attaining the same degree as that observed in those who are born on the high plateaus. This phenomenon, which has been repeatedly verified, is difficult to explain on the ground of a nervous influence, as the general stimulating effect on the nervous system be-

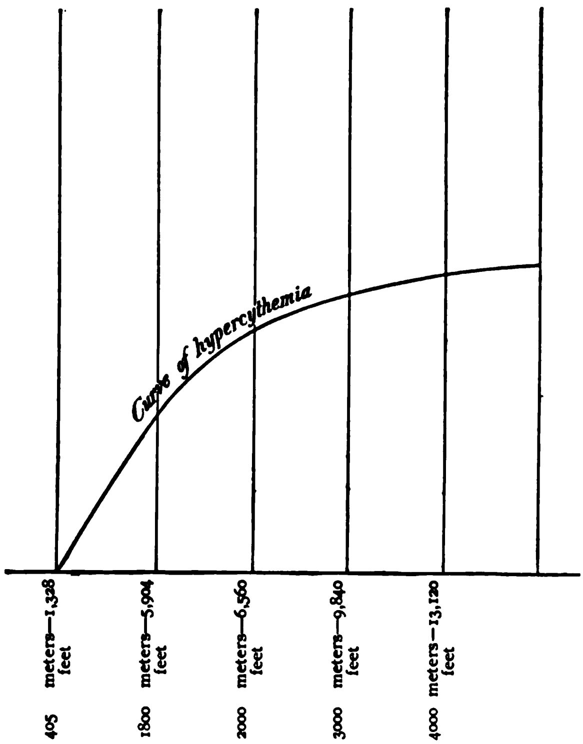

FIG. 17.—EFFECT OF ELEVATION ON THE NUMBER OF COLORED CELLS.

comes progressively more feeble, so that in a short time it is practically negligible.

(*b*) A veritable crop of dwarf-cells is produced, as in cases of regeneration after the withdrawal of large quantities of blood. This explains why the percentage of hemoglobin does not increase with the same rapidity as the number of erythrocytes, the young cells being much less rich in hemoglobin than adult cells. In man it is by means of this process that blood-loss is repaired, as Hayem has so well shown.

It cannot be said that the final explanation of the permanent hypercythemia observed at high altitudes has been reached; future investigations will no doubt modify some of its details, but for the present the theory of a **true increase in the number of the erythrocytes** seems the most tenable. The principal factor in the production of this change is the **diminution of the barometric pressure.**

This is well shown by the following experiment of Regnard: A guinea-pig was confined for a month in a bell-jar in which a constant low pressure was maintained. To guard against any possible danger from intoxication through the animal's excretions, it was transferred every day to another apparatus in which exactly the same conditions prevailed. The guinea-pig did not enjoy the benefit of bracing and stimulating mountain air; its appetite was rather below than above normal; it was simply subjected to a pressure approximately equivalent to the barometric pressure prevailing at the Col du St. Bernard, or at Santa Fé de Bogota, altitude 2000 meters (6560 feet). At the end of the month the animal's blood was found to absorb 21 per cent. (by volume) of oxygen, which very nearly represents the coefficient of absorption of the blood of llamas living near La Paz; whereas guinea-pigs enjoying their full liberty and placed under much better hygienic surroundings showed an absorbing power of only 14 to 17 volumes per cent.

Sellier, of Bordeaux, went even further, and conclusively proved that the absolute degree of pressure is without influence on the result, the important factor being the **diminution in the tension of the oxygen.** Three different experiments were made on birds. In the first, the birds were confined for a number of days in rarefied air; in the second, they were placed in an artificial atmosphere having an entire pressure of 76 centimeters of mercury (normal barometric pressure), but in which the oxygen tension was reduced to equal that prevailing at the Pic du Midi; in the third experiment the tension of the oxygen was normal, but the tension of the inert gas was diminished so that the total pressure was less than 76 centimeters of mercury. It was found that in the first and second experiments hypercythemia was produced, while in the third experiment this hemic reaction failed to appear.

Conversely, an **increase in the oxygen tension** is followed by the disappearance of a certain proportion of red blood-cells which have become useless for purposes of respiration. This was to have been expected *à priori*, and further experimental proof has been furnished by Doyou and Maurel, who observed a distinct diminution in the number of erythrocytes in animals subjected to the continuous action of condensed air.

Cazeaux gives the following figures for the number of red cells at altitudes ranging between 450 and 1800 meters—1476 to 5904 feet:

On the plain,		5,000,000
At 450 meters,	476 feet,	5,800,000
" 700 "	2296 "	5,900,000
" 950 "	3116 "	6,100,000
" 1800 "	5904 "	7,100,000

In the case of **tuberculous** subjects—and it may be observed in passing that the beneficial influence of high altitudes manifests itself also in the case of anemic, alcoholic, and neurasthenic patients—the degree of hypercythemia is usually constant, while the increase in the hemoglobin does not follow a parallel course. Meisser and Schröder observed that the hemoglobin continues to increase in phthisical patients who are improving or recovering; it remains stationary or diminishes when the disease is tending toward a fatal termination; and when the progress toward recovery is arrested in subjects who had been improving, the percentage of hemoglobin rapidly falls in almost exact accord with the progress of the disease.

The facts that have thus been briefly reviewed give us an inkling of the **mechanism** by which the animal organism, when forced to live in a rarefied atmosphere, adapts itself to the altered conditions. They furnish a much more plausible explanation of the tolerance for sudden changes of altitude manifested by birds, than the theory which assumes that they possess a reserve supply of air in their pulmonary vesicles.

The power of adaptation to different altitudes, within certain limits, is a general biologic law. Gaston Bonnier, in 1890, studied the phenomena of such adaptation in plants, and demonstrated the modifications that they undergo in the process. The parts under the ground accumulate an increased supply of nourishment; the stems become shorter, the leaves more abundant, greener, and richer in coloring-matter. The latter phenomenon, the increase in the chlorophyl in the external portions of the plant, on account of its analogy with the changes that occur in the hemoglobin, is the principal point to be remembered.

THERAPEUTIC APPLICATION

The therapeutic employment of naturally rarefied air pertains to the domain of **climatology,** and may be referred to only incidentally in this connection. The reduction of barometric pressure is far from being the only factor in mountain cures; the success of which depends on a variety

of conditions, such as the cold, the greater intensity of the sunlight, the purity of the air, isolation, rest, and alimentation,—rendering the question extremely complex. (See volumes III and IV.)

The lowering of the **temperature,** in the shade, increases with the altitude, but the relation is quite irregular. On the Ventoux the temperature falls 1° C. (1.8° F.) for every rise of 141 meters (462 feet); on the St. Gotthard for every 168 meters (551 feet); on the St. Bernard for every 188 meters (616 feet). The heat that prevails during the winter in elevated regions is explained by the fact that the cold air, being heavier, descends into the valleys and forms mists and fogs, while the air at the top of the mountain, being hotter, expands, does not approach the dew-point, and thus preserves its brilliancy.

The following figures are taken from Frankland:

	ALTITUDE	SHADE	SUN
Oatland Park (England), ...	46 meters— 140 feet	30.0%	61.5%
Pontresina (Switzerland), ...	1800 meters—5904 feet	26.5%	44.0%
Bernina Hospice (Switzerland), ...	2330 meters—7642 feet	19.1%	46.4%

Owing to the transparent quality of the air and the absence of aqueous vapor, the **light** in high mountain regions is marvelously brilliant, especially in winter, when full sunlight lasts three to four hours in January, four to five in February, and more than seven hours in March. The radiation of colored beams gives rise to magnificent sunrise and sunset effects; and the chemical rays appear to possess greater force, since photographers assert that shorter exposures are required (Cazeaux) (see also vol. IX, "Phototherapy.") In regard to the **purity of the air,** Miquel and Freudenreich found that the microphytes diminish rapidly with the altitude and disappear at 2000 meters (6560 feet). Christiani in a balloon-ascension was unable to demonstrate their presence at 1000 meters (3280 feet).

Mountain Cures

Mountain cures are recommended chiefly in the treatment of **pulmonary tuberculosis,** but it is well to note that good results are obtained in other conditions also, such as **anemia, convalescence** from acute disease, **neurasthenia,** and the like,—adding the caution, however, that such patients should be sent to some point not frequented by consumptives. For a long time a high altitude was regarded as essential for a sanatorium for the tuberculous; and a number of authors, including especially Jaccoud, still insist on the necessity of an elevated situation, although it has recently been demonstrated that high altitude in itself

confers no immunity against tuberculosis. On the other hand, some authors contend that the question of actual elevation is immaterial, and that the hygienic factors—fresh air, superalimentation, and rest—are the essential points in the treatment (Sabourin, Petit, Knopf). It is not to be denied that all phthisical patients are not equally amenable to a mountain cure, that there are certain distinct counterindications to the treatment, and that the special features of different climates must be taken into consideration (Fremy). Nevertheless the general statement holds good that the mountains are usually better than the plains; the air is purer, the light more intense, the soil is dry, the temperature although low is more equable, and the winds are less severe (Petit, Cohen).

The choice of the **degree of elevation** is important; but must here be dismissed with such brief comment as is absolutely necessary. One point to be borne in mind is that the therapeutic possibilities of the same altitude vary in different regions. According to Sir Hermann Weber, a chain of mountains 500 to 700 meters (1700 to 2300 feet) high, situated in the flat, cold regions of northern Germany, possesses the vegetation and all the climatic features of a mountainous country, even in its valleys. On the other hand, a much lower elevation in the Himalayas and in the Peruvian Andes would not be called mountainous, since in these ranges cereal fruits and fruit trees only begin to grow at an elevation of 1000 to 1500 meters (3280 to 4920 feet), while the timber-line corresponds to an elevation above 4000 meters (13,120 feet). It may be said in general, that in northern latitudes and in table-lands far from the sea, mountain climate in the climatotherapeutic sense begins at 500 to 600 meters (1700 to 2000 feet); while a much greater altitude is necessary in more southerly latitudes—that is, near the equator—and in very extensive plateaus. The **highest limit** for the therapeutic utilization of mountain climate under ordinary conditions varies therefore according to the degree of latitude and other isothermal influences. It should rarely exceed 1000 meters (3280 feet) in the northern portions of the temperate zone; while in the intermediate portions, as the Swiss Alps, it may be placed, under favorable conditions, as high as 2000 meters (6600 feet); and in the tropical zone, as, for example, in the Peruvian Andes, it rises above 3000 meters (9900 feet), and, in the treatment of certain conditions, above 4000 meters (13,000 feet).

This part of the subject calls for much more detailed and extensive exposition, for which the reader is referred to the works of Regnard, which contain much interesting information; and to the volumes of this series (III and IV) specially devoted to climatology.

CHAPTER VI

DIFFERENTIAL PRESSURE METHODS

Respiratory Differentiation—Apparatus: Hauke, Berkart, Dobell's Residual Air-pump, Waldenburg, Schnitzler's Single Apparatus, Tobold Cube, Weil, Schnitzler's Double Apparatus, Goebel, Finkler and Kochs, Biedert, Leiter, Fraenkel, Stoerk, Treutler, Geigel and Mayer, Hogyes, Dupont, Cohen's Apparatus for Home Use, Cohen's Apparatus for Hospital Use, Cohen's Resistance Valves, Ramadge Tube, Spirometers. Hyperdistention of the Pulmonary Alveoli. External Differentiation—Methods of Differentiation without Apparatus: Valsalva's Experiment; Müller's Experiment; Weber's Experiment; Gerhardt's Procedure. Apparatus: Hauke, Williams and Ketcham, Cups, Junod's Boot. Politzerization. Catheterization of the Middle Ear.

THE COMPOSITION OF THE AIR REMAINS THE SAME, BUT THE PRESSURE UPON (A) THE RESPIRATORY OR (B) THE EXTERNAL SURFACE OF THE BODY IS MODIFIED GENERALLY OR PARTIALLY—DIFFERENTIAL PRESSURE

The general purpose of the pneumotherapeutic methods included in this class is to bring about a differentiation of pressure between the external surface of the body and the respiratory surface; or between the two phases of respiration; or to combine these procedures. This may be accomplished (*a*) by modifying the pressure of the air respired by a patient immersed in the ordinary atmosphere—**respiratory differentiation**; or (*b*) by modifying the pressure of the air in which a patient is immersed while respiring the ordinary atmosphere—**external differentiation.** Respiratory differentiation * may be made to affect one phase of respiration only (**monophasal,** inspiratory or expiratory); or both phases similarly and equally, or both phases dissimilarly or unequally (**diphasal,** constant or alternating, uniform or variant). External differentiation may affect the whole surface of the body (**general**); or a restricted portion of the surface (**partial**); or several portions, equally or

* See editor's scheme of Pneumotherapeutic Methods, page 55.

unequally (**multiple,** uniform or variant). As the principal obvious difference between the stationary pneumatic chamber described in a previous chapter and apparatus of the class here considered is that the latter, besides being less costly, can be transported from place to place, the expression **portable apparatus** has become practically synonymous with **differential pressure apparatus,** more particularly of the respiratory type. This misuse of terms, however, should be avoided.

RESPIRATORY DIFFERENTIATION

S. Solis Cohen gives the following general description of the methods of respiratory differentiation: Atmospheric pressure upon the exterior surface of the body remaining unchanged, **increase of pressure** upon the surface of the air-passages—pulmonary surface—may be obtained (1) by inspiration of condensed air, and (2) by expiration into condensed air; **decrease of pressure** upon the pulmonary surface may be brought about (1) by expiration into rarefied air, and (2) by inspiration of rarefied air. These procedures—**monophasal differentiations**—may be so combined as to maintain the increase or decrease during both phases of the respiratory act—continuous respiration of modified air—**diphasal consistent** (uniform or variant) **differentiation**—or to allow of increase during one phase and decrease during the other—respiration of alternately modified air—**diphasal alternating** (uniform or variant) **differentiation**. There are thus eight principal methods of respiratory differentiation, which may be tabulated as follow:

Inspiration of:	With Expiration into:
1. Condensed air	Atmosphere
2. Condensed air	Condensed air
3. Condensed air	Rarefied air
4. Rarefied air	Atmosphere
5. Rarefied air	Rarefied air
6. Rarefied air	Condensed air
7. Atmosphere	Condensed air
8. Atmosphere	Rarefied air

Additional variations may be made by alternating any one of the methods with any other, or by following one with another. For example, procedure No. 2 may alternate with procedure No. 3 or with procedure No. 6, and so on. The expedients found most useful in practice, and that are accordingly in most general employment, are those numbered respectively 3, 4, and 8.

Before discussing the physiologic effects and therapeutic application

of differential pressure methods, the principal forms of apparatus employed for this purpose will be described.

DIFFERENTIAL PNEUMATIC PRESSURE APPARATUS

APPARATUS IN WHICH CONDENSATION AND RAREFACTION ARE EFFECTED BY MEANS OF A BELLOWS OR FORCE-PUMP COMMUNICATING WITH A RESERVOIR

Hauke's Apparatus.—At the head of the list of inventors of pneumotherapeutic apparatus is the name of Hauke. Hauke's apparatus (Fig. 18) is composed of a cylinder divided into two parts by a vertical partition, the two compartments communicating at the bottom. A quantity of water sufficient to fill one of the compartments, which is closed at the top, is poured into the instrument; the other compartment is provided at the top with two openings closed by a stopcock; by means of one of these openings the air is condensed either with bellows or with a force-pump; the other is fitted with a tube which terminates in a mask which the patient applies to his mouth. Hauke employed the inspiration of air compressed in this manner to combat the dyspnea of diphtheritic laryngitis, in which it was not always successful. On the other hand, he had every reason to be satisfied with his results in pulmonary tuberculosis, and especially in emphysema, which, according to him, could be completely cured by this method of treatment. The same instrument could easily be used for the rarefaction of air by adding an aspirating pump to the upper portion of the water compartment. But this apparatus, ingenious and simple as it is, is open to two serious objections: the difficulty of bringing about a sufficient degree of modification of the air-pressure and the impossibility of regulating accurately the condensation or rarefaction attained.

FIG. 18.—HAUKE'S APPARATUS.

Berkart's apparatus, next in order historically, will be considered in

a more appropriate connection—it was not an improvement upon Hauke's.

APPARATUS CONSTRUCTED ON THE GASOMETER PRINCIPLE

Waldenburg's Apparatus.—Waldenburg solved the problem by reverting to the plan of Beddoes and Watt and applying the principle of the gasometer to differential pneumotherapy. Waldenburg's model of 1873 (Fig. 19) consists, in the main, of two concentric reservoirs of sheet-iron. The outer cylinder, which is closed at the bottom, is 1 meter (39 inches) high and 30 centimeters (12 inches) in diameter. The inner cylinder, which glides on the outer one, is open at the bottom and measures 1 meter in height and 25 centimeters (10 inches) in diameter. The upper portion of the outer cylinder is surmounted by a cylindrical cap 10 centimeters (4 inches) in height, but wider than the cylinder, so as to overlap a little more than 5 centimeters (2 inches). Water is poured into the apparatus so that, when the inner cylinder is forced down into the outer cylinder, the apparatus is filled to the brim, the cylindrical cap at the top of the outer cylinder being destined to receive the water that overflows when the inner cylinder descends. The inner cylinder is moved up and down by means of weights and pulleys. At the outer circumference of the cap surmounting the outer cylinder are attached three metallic rods, a little more than a meter in length, connected by a metal ring a short distance from their upper extremities. Each rod is supplied with a pulley and cord, one end of which—the outer—carries a hook to which weights can be attached, while the other extremity is fastened to a horizontal bar of metal, one end of which rests on the

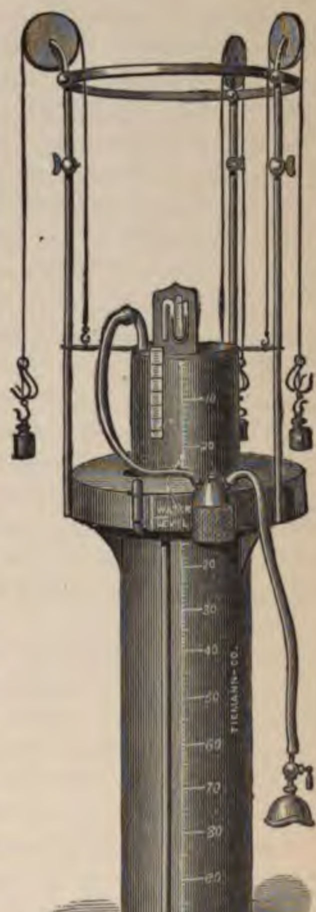

FIG. 19.—WALDENBURG'S APPARATUS.

top of the inner cylinder, while the other terminates in a fork which slides on the metallic rods so as to insure greater regularity in the movements.

To rarefy the air, weights are attached to the hooks on the cords; to compress the air, weights are placed on the roof of the inner cylinder before it is filled with atmospheric air. In order to prevent the inner cylinder from rising too high, a movable stop is attached to each of the rods at a height of about 0.85 m. ($33\frac{1}{2}$ inches). The top of the inner cylinder is perforated by two orifices, one of which communicates with a mercury manometer graduated to 40 millimeters ($1\frac{1}{2}$ inches) in each direction, and the other communicates by a tube with a mask that is used for respiration. A stopcock in the bottom of the outer cylinder permits the water to be drawn off. A glass tube graduated in centimeters extends from the bottom to the top of the cylinder, and enables the operator to ascertain the level of the water in the cylinder at any time. The inner cylinder is also provided with a centimetric scale, and when the apparatus is to be used as a spirometer the volume of that portion of the cylinder which does not contain water is indicated on the scale. A two-way stopcock attached to the mask and interposed between it and the air-chamber enables the patient to breathe at will either the modified air of the inner cylinder, or atmospheric air; and thus to regulate his respiration according to the physician's orders.

The masks are made in three sizes, of spun metal with pneumatic rubber cushions so that they may fit hermetically over the patient's nose and mouth. If there is some leakage at first, the mask, which is slightly malleable, can be molded to fit the patient's face. It is always possible to obtain perfect closure, unless the beard is too abundant. One may easily determine whether closure is perfect or not. When compressed air is used and the communicating stopcock is opened, the inner cylinder should not descend so long as the patient does not make an inspiration; when rarefied air is used, the cylinder ought not to rise before the patient begins to exhale. To avoid danger of contagion, and as a matter of good taste, it is best to have an individual mask for each patient.

Waldenburg's apparatus has been deemed worthy of detailed description, as it has probably been used more frequently than any other. It possesses numerous advantages: A high degree of compression or rarefaction may be obtained with it; the pressure, whether positive or negative, can be regulated readily and accurately; the apparatus can easily be used by the patient himself without an attendant after he has been taught by a single sitting. By means of a Woulff bottle suitably connected the air may be moistened or dried, warmed or cooled, or the

inhalations may even be medicated by means of volatile substances (Cube).*

When expiration is made into one of Waldenburg's cylinders, a Woulff bottle containing a disinfecting solution may so be interposed as to avert any danger of infection, should the same instrument be used in succession by several patients both for inspiration and for expiration. It is much better, however, to have two cylinders; using one for inspiration only and the other for expiration only.

Numerous attempts have been made to improve the details of construction in Waldenburg's apparatus, and some of these attempts have not been without success. They consist in certain modifications in the system of pulleys, in the stopcock,—as, for example, Cohen's modeled on the cornet-piston; in the mask, which may be made wholly of hard or soft rubber, or of glass with or without rubber cushions (see page 294); and—as, for instance, the device of Cube—in the addition of attachments that allow a more extended use of the apparatus. An attempt has also been made to increase the volume of the apparatus, but in Waldenburg's view this is a questionable advantage; because he believed that the duration of a séance, which he had accurately calculated in the construction of his apparatus, could not be prolonged without untoward results.† One of the chief defects of Waldenburg's original model is the fact that it must be used either for condensed air alone or for rarefied air alone; but this is easily remedied by employing two cylinders, as previously suggested.

Schnitzler's Single Apparatus.—In regard to accuracy of operation and constancy of pressure Schnitzler's modification possesses all the advantages of Waldenburg's model, the differences being such as have been suggested by many years' practical experience for greater convenience in handling the apparatus. Thus, the guiding rods that control the movement of the inner cylinder are attached to the body of the outer cylinder, instead of to the top; the arrangements for altering the positive or negative pressure by means of weights are more convenient; the breathing tube, instead of issuing from the lid of the inner cylinder, is attached to the base of the outer cylinder and passes thence to the inner cylinder. The apparatus is also provided with appliances

* Thus, Domanski has observed good results in bronchitis and pulmonary tuberculosis from inhalations of compressed air, medicated with essence of turpentine or a 1 per cent. solution of carbolic acid. Formalin, myrtol, eucalyptol or any volatile medicament desired may be used similarly.

† The editor, however, by means of his continuously acting apparatus has prolonged a differential respiration far beyond Waldenburg's limit, with good effect. Caution must be observed, however, in such prolonged sittings and skilled supervision is necessary.

for testing the inspired air and for charging it with gases; and by counterbalancing the inner cylinder, the apparatus may be used as a spirometer, while the manometer is so constructed that it can be made to serve as a pneumatometer.

Tobold's apparatus (Fig. 20), much like Schnitzler's, is a simplified form, and has the advantage of being smaller and less costly. It also has a special attachment for warming the inspired air.

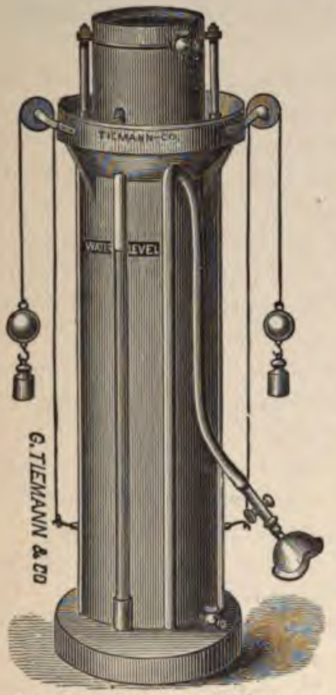

FIG. 20.—TOBOLD'S PNEUMATIC APPARATUS.

Double Gasometer Apparatus

It is sometimes useful to be able to affect both phases of respiration either in the same or in opposite directions; as by **continuous respiration** of condensed or rarefied air or by **alternation** of positive or negative pressure—condensed air during inspiration and rarefied air during expiration, or *vice versa*. This suggested the idea of double cylinders, which, however, are heavier, more bulky, more expensive, and less readily transported than single apparatus. With the double apparatus there is less risk of contagion than with single cylinders that are used first during expiration for one patient and then again during inspiration for another. One must admit, however, that the danger referred to is apt to be exaggerated. If the air is filtered at a well-chosen point, especially if an **individual mask** is used for each patient, Waldenburg's apparatus is perfectly safe. Double apparatus have been proposed by Cube, Weil, Schnitzler and others. One of the most practical is that devised by Schnitzler, which is extensively used in Europe.

Cube's double apparatus is built on a larger scale than others of this type, and therefore has the disadvantage of being less readily transported; on the other hand, the pressure is more constant. One of the cylinders is used exclusively for inspiration, the other for expiration; the two can be connected and used together, or each can be used separately (Fig. 21).

Weil's double apparatus (Fig. 22) consists of two Waldenburg cylinders

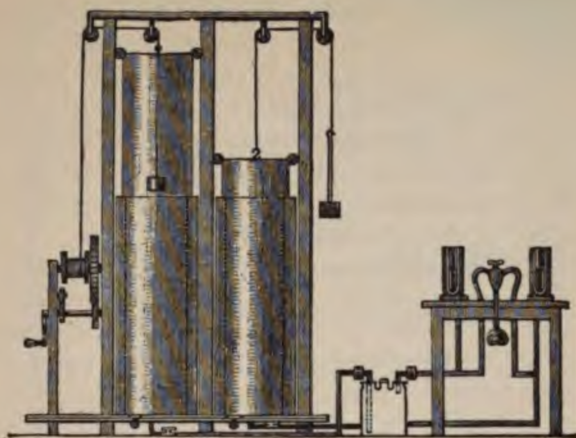

FIG. 21.—CUBE'S DOUBLE APPARATUS.

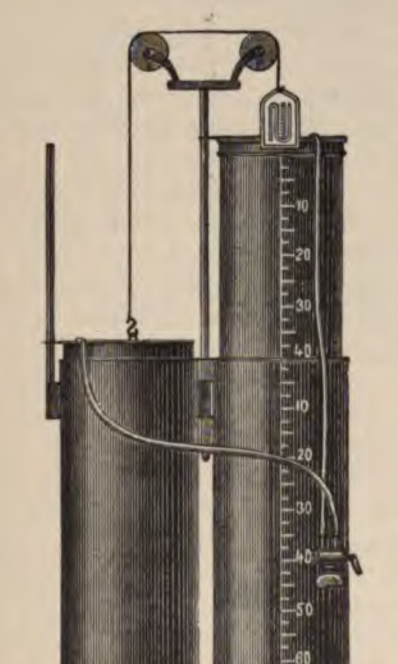

FIG. 22.—WEIL'S DOUBLE APPARATUS.

connected at the bottom by a short rubber tube in such a way that one cylinder rises as the other descends, so that one or the other is constantly ready for use. Weil's apparatus is designed for the **continuous use** of condensed or rarefied air, rather than for alternating respiration. The two breathing tubes communicate with a double stopcock which has two openings, and by turning the stopcock half-way one of the cylinders is made to rise or descend. The respirations are regulated by another stopcock attached to the mouthpiece (Fig. 23).

Schnitzler's Double Apparatus.—This can be used for the continuous inhalation of condensed air, or for continuous expiration into rarefied air, or for the alternating and intermittent use of condensed air and rarefied air, and, finally, as a pneumatometer and spirometer. The two cylinders, open at the bottom, which, with a large oval receptacle, make up the apparatus, are so arranged that as one of them descends the other rises to a corresponding height; the air in the falling cylinder is therefore condensed while that in the rising cylinder is rarefied. By means of a revolving, perforated disk the breathing tube can be instantly connected to one or the other cylinder as desired.

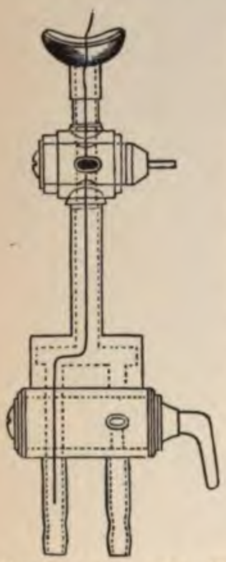

FIG. 23.—DIAGRAM OF WEIL'S DOUBLE TWO-WAY STOPCOCK.

Goebel's apparatus, or so-called system of pneumatic cabinets (a misnomer), has been in use at Ems for a number of years. It consists of two separate and independent double apparatus, one for condensed and one for rarefied air. Each apparatus consists of two cylinders, connected by a wire rope which passes over a large wooden pulley as shown in the accompanying figure * (Fig. 24). By means of a cog-wheel attached to the pulley and a driving-rod, one of the cylinders is raised as the other is depressed by the iron weights attached; so that one of the cylinders contains condensed and the other rarefied air. The desired degree of condensation is maintained by a regulator in communication with the two cylinders. Provision is made for filtering the air and maintaining it at the proper temperature by heating or cooling according to the season of the year. The renewal of the water in the cylinders is effected automatically. When the two machines which constitute the entire

* "Neue Heilmittel," etc., by Ed. Aronsohn, "Deutsche Medizinal-Zeitung," 1890.

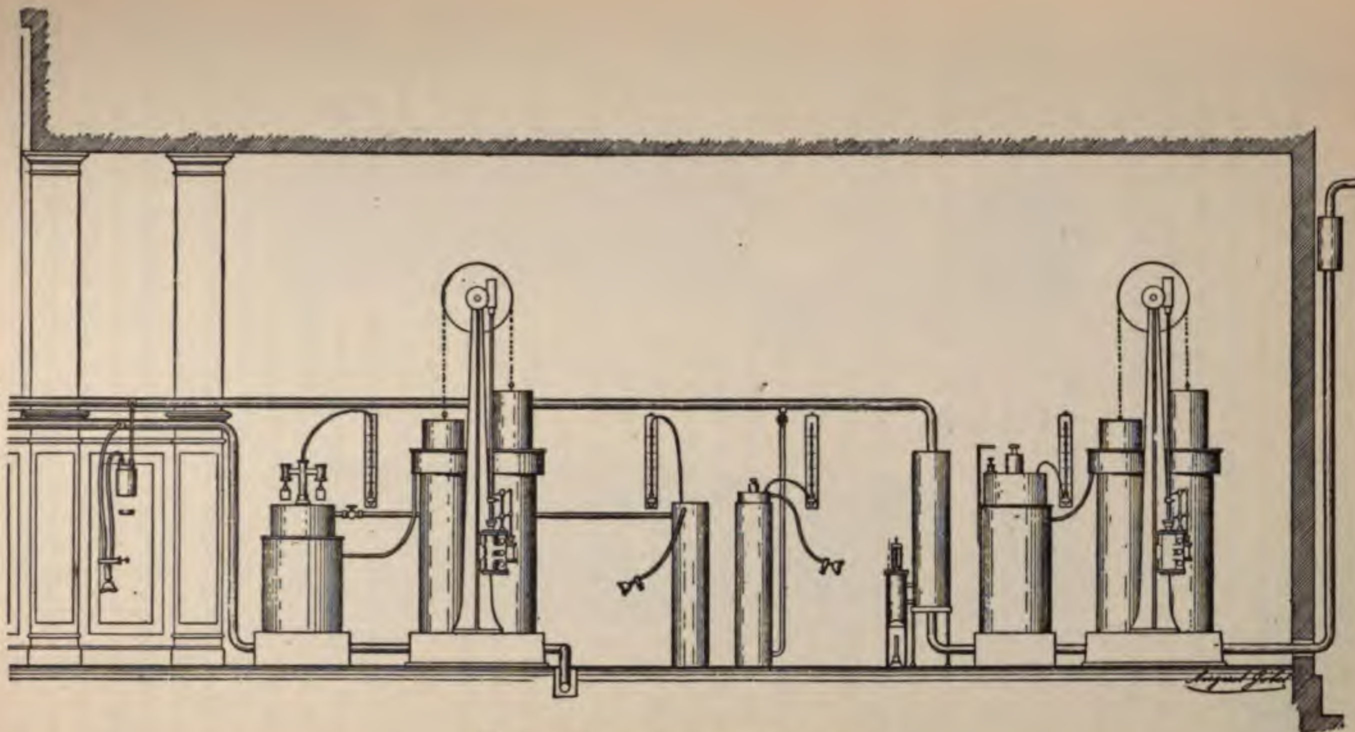

FIG. 24.—GOEBEL'S PNEUMATIC CABINET.

installation are working, the following procedures are possible for seven patients at the same time:

Inspiration of condensed air with expiration into ordinary air.

Inspiration of ordinary air with expiration into rarefied air.

Inspiration of condensed air with expiration into rarefied air.

Inspiration of condensed air mixed with volatile medicinal substances and expiration into rarefied air.

The advantages of Goebel's double apparatus are that they work automatically, the power being derived from the municipal water system; that the water is renewed automatically; and that the two apparatus are entirely independent of one another, so that there is no possibility of the inspired air being contaminated by passing through pipes that have been utilized for expired air.

Apparatus of Finkler and Kochs.—With this apparatus (Fig. 25) condensed air is forced into the lungs during inspiration, expiration being assisted by withdrawal of air from the lung.

It consists of a large cylindrical receptacle for water, measuring 25 centimeters in diameter. The base of this cylinder is pierced by two large pipes *r′* and *r*, the internal diameter of which is 1.5 centimeters. The large receptacle accommodates a **double cylinder** or bell, supported by a chain that passes over a wheel and counterbalanced by weights. The inner cylinder measures 35 centimeters in height and 16 in width. The outer cylinder surrounds the inner like a ring and measures 70 centimeters in height and 40 in width. The inner cylinder is provided with the pipe *k*, the valve of which opens inward, and communicates with the mask by means of the pipe *r*. The outer cylinder is provided with a valve which opens outward, *d′*; the pipe *r′* connects the outer cylinder with the mask. The pipes *r* and *r′* are inserted into rubber tubes which communicate with the mask by means of a T-shaped attachment. These rubber tubes are provided with a double clamp permitting one tube to be compressed while the other remains open. The apparatus is filled with water through the opening *n*, which is then closed with a rubber stopper. The chain-wheel consists of two concentric pulleys mounted on the same axis; the inner supports the cylinder, the outer one the weights. As the radius of the outer pulley is twice that of the inner, half the weight of the cylinder suffices to counterbalance it.

By attaching additional weights to the outer chain the double cylinder is made to rise; at the same time the valve *d′* closes and the valve *d* is opened. If the rubber tube attached to *r*, which leads from the inner cylinder to the mask, is compressed at the same time, and the rubber tube attached to *r′*, which leads from the outer cylinder to the mask is

opened, the outer cylinder will withdraw air from the mask (or lungs) by suction, while the inner cylinder becomes filled with air through the open valve *d* from the atmosphere. If, on the other hand, the weights are raised (by the handle), the double cylinder falls of its own weight. Then, if the rubber tube attached to *r* is opened and the tube attached to *r′* closed, the air will be forced from the inner cylinder through the tube

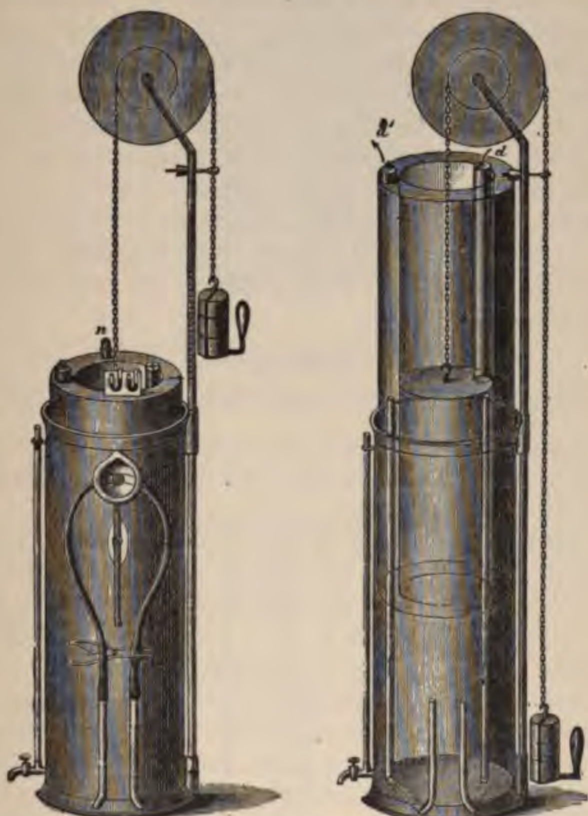

FIG. 25.—APPARATUS OF FINKLER AND KOCHS.

into the mask, and therefore into the lungs; while at the same time the air escapes from the outer cylinder through the open valve *d′*. It follows, therefore, that, during the descent of the cylinders, the air that had previously entered the inner cylinder through the valve *d* is discharged into the lungs through the pipe *r;* while the air that had previously been withdrawn from the lungs through the pipe *r′* escapes from the outer cylinder through the valve *d′*. The degree of rarefaction and compres-

sion can be regulated by changing the counter-weights and by increasing the weight of the double cylinder by the addition of pieces of lead. Thus, a negative pressure of —2 centimeters, and a positive pressure of +2 centimeters of mercury can be attained. To each cylinder is attached a manometer indicating the pressure in that cylinder. The maximum counterweight required for balancing the cylinders is about 5 kilograms (11 pounds). The greatest distance traversed by the counterbalancing weights is 70 centimeters (27 inches).

When the apparatus is used as a **spirometer** to measure the quantity of air that can be expired after the fullest possible inspiration, the valves are removed and the openings closed with rubber stoppers. The subject is then directed to expire while the mask communicates with the pipe *r'*, when the tube is immediately compressed; the weights are then raised until the manometer of the outer cylinder stands at 0 and the quantity of expired air, up to 50 centimeters, can be read off in cubic centimeters on the scale attached to the iron rod. **Bayer** has constructed a somewhat similar apparatus.

APPARATUS CONSTRUCTED ON THE BELLOWS PRINCIPLE

The apparatus devised by Biedert and Fraenkel are based on the principle of a bellows; the advantages and disadvantages of these apparatus will be discussed presently.

Biedert's apparatus is based on the principle of the musical instrument commonly known as a harmonica, to one extremity of which weights are affixed (Fig. 26). The instrument is described by Rose as follows: * The bellows has the form of a cylinder, 50 centimeters (20 inches) in height, 22 centimeters (9 inches) in diameter, which is closed at the ends by boards 1.5 centimeters (⅝ inch) in thickness, termed covers. Its walls are made of leather, air-tight, and have the necessary strength to maintain their original form against overpressure of air. The lower cover has a perforation near its front margin into which a rubber tube is fitted air-tight, and when in use is prevented from collapsing by a spiral wire which it contains. Straps are fastened crosswise to the upper cover for holding weights; pins being inserted which fit into holes in the weights and prevent their slipping. These weights are round plates of iron of the diameter of the covers of the bellows; two are 2½ pounds (1.25 kilos) each, and others 5 pounds (2.5 kilos) each; 30 pounds (15 kilos) go with each apparatus. When the bellows is expanded as much as possible,

* Cited by J. Solis-Cohen, "Inhalation," 2d edition, 1876, p. 49.

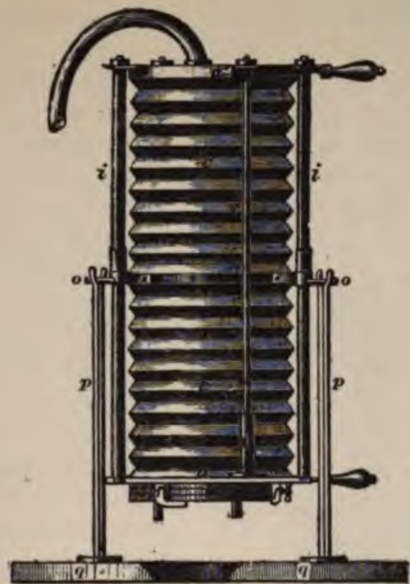

FIG. 26.—BIEDERT'S APPARATUS. POSITION I.

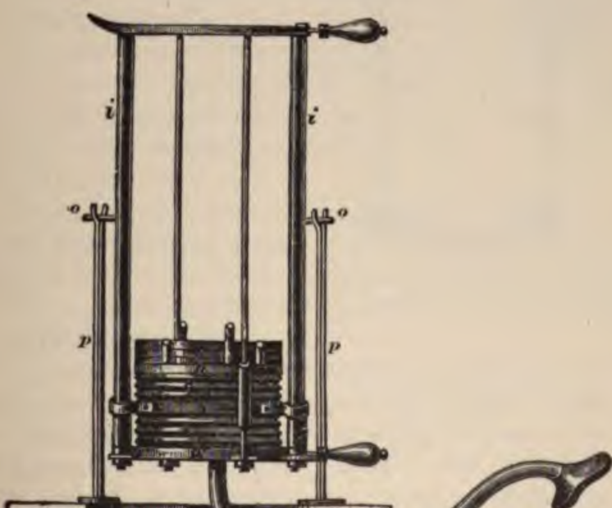

FIG. 27.—BIEDERT'S APPARATUS. POSITION II.

it contains a column of air the diameter of which is, upon an average, 2 centimeters ($\frac{3}{4}$ inch) less than that of the covers, on account of the zigzag outline of the walls of the bellows. The pressure which the covers of the bellows must support is equal to that upon a circular plane 20 centimeters (about 8 inches) in diameter, or 314 square centimeters of area (corresponding area in square inches, 50$\frac{1}{4}$), which will be 648 pounds (324 kilos), taking 1033 grams as the pressure upon a square centimeter (12.8 pounds on a square inch). If the bellows is charged with 1 pound (0.5 kilo), the condensation of the air will be $\frac{1}{648}$; with 10 pounds (5 kilos) it will be $\frac{1}{64}$; with 20 (10 kilos), $\frac{1}{32}$; with 30, $\frac{1}{21}$. If the bellows is reversed, weights downward, and in this manner expanded, the cubic contents will be equal to the area of the cover multiplied by the height of the expanded bellows, $314 \times 50 = 15{,}700$ cubic centimeters (980 cubic inches).

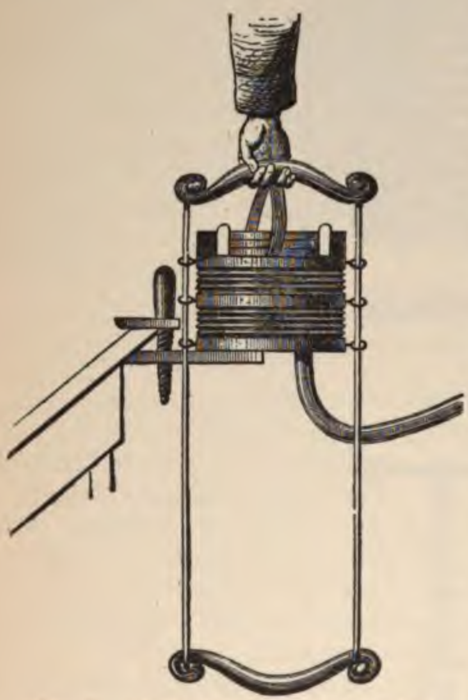

FIG. 28.—SIMPLIFIED FORM OF BIEDERT'S APPARATUS. POSITION II.

The other part of the apparatus is a stand of iron consisting of four opposite iron bars, two thinner (*h*) and two stronger (*i*), connected on top by a flat ring, the diameter of which is 24 centimeters (about 9 inches). The lower ends of the bars are fastened to the lower cover of the bellows, which can readily be removed. The upper cover of the bellows can be moved up and down, and is kept in line by guides running on the two upright thin bars of the stand. Guides are also attached to the body of the bellows, which slide on the two stronger upright bars. Small projecting pins (*o*) are attached to the centers of the larger bars, upon which the whole apparatus swings. These pinions are supported upon uprights (*p*) from a firm base of wood (*q*). Upon the pinions the apparatus can be turned by two handles, one of which projects from the ring above, the other at the lower end

from one of the bars. This arrangement permits a half-turn of the apparatus backward.

Method of Employment.—The machine is placed upright on the margin of a table, so that the tube will be in a groove cut into the wooden base, and the desired quantity of weights is fastened to the upper cover of the bellows. If the upper end is turned down, the weights will sink and the bellows will fill itself with air. The bellows is then turned back, while the patient compresses the rubber tube with his fingers until he is ready to inhale through the mouthpiece attached; he then gradually inhales the air as the weights compress the bellows. While the patient expires into the free air the bellows is filled again by turning, and the operation continued in this manner indefinitely. For expiration into rarefied air, the tube is compressed and the bellows turned weights downward; applying the tube to the mouth, the air passes from the lungs into the partial vacuum produced by the expansion of the bellows. The bellows filled with the expiratory air is emptied by turning, while the patient inspires air at the atmospheric pressure, and the operation is repeated.

Finally, the patient can inhale condensed air from the partially filled bellows, and after turning the apparatus exhale directly into rarefied air.

Leiter has constructed a double-acting apparatus by combining two apparatus identical with the one which has just been described, in one of which the air is condensed, while in the other it is rarefied.

FIG. 29.—FRAENKEL'S APPARATUS.

Fraenkel's Apparatus.—Fraenkel's apparatus (Fig. 29) resembles the musical instrument known under the name of an accordion. I am again indebted to J. Solis-Cohen's book * for the following description, which is more complete and more accurate than I could obtain from the book of the author himself.

On one side is inserted a metal tube 2 centimeters in diameter, which carries the mouthpiece; the latter may consist of an inflated rubber cushion, similar to a pessary. Fraenkel recommends the sitting position for using the apparatus. If the bellows is expanded by drawing the accordion apart, the air contained in it will be rarefied; if it is compressed, the air is condensed. If the patient, during

* "Inhalation: Its Therapeutics and Practice," Philadelphia, 1876.

the expansion or compression, applies his mouth to the cushion, the effect of the rarefaction or condensation of the air will communicate itself to the intrathoracic air. The appliance is without valves, as it is very easy to apply or withdraw the mouth from the cushion at the right moment; any such arrangement as valves is therefore not necessary. If expiration is to be made into rarefied air, the mouth should be applied to the cushion and the bellows expanded. After the expiration the mouth is withdrawn from the cushion, and, while inhaling the free air, the patient closes the bellows; for expiring, the apparatus is found empty and ready.

On the margin of the instrument is a centimetric measure, which plainly indicates by how many centimeters the wooden disks are separated or brought together. This shows the volume of air which has been drawn into or expelled from the apparatus. The apparatus is 35 centimeters ($13\frac{1}{2}$ inches) in height and 16 ($6\frac{1}{4}$ inches) in breadth. If the foldings are considered, the bottom area will be $15 \times 34 = 510$ square centimeters ($77\frac{1}{2}$ square inches). A linear expansion of the accordion of one centimeter, according to the measure affixed, would correspond with 510 centimeters of volume.

Fraenkel considers the attachment of the dynamometer to his instrument unnecessary.

All varieties of effects described with Biedert's apparatus can also be produced with Fraenkel's device, by the patient himself, without assistance. He can either inspire condensed air only, or he can inspire condensed air and expire into rarefied air.

Owing to the shortness of the breathing-tube, the air from this apparatus is more completely and fully received by the lungs, and with less modification of its original pressure, than by any previous invention. All excess of action is avoided, as it is worked by manual force only, Fraenkel having found that with his greatest efforts he could not condense the air above $\frac{1}{18}$ of an atmosphere, nor the power of suction above $\frac{1}{20}$ atmosphere. The patient is sensitive to the amount of pressure and draft upon his lungs, and can regulate both according to his own feelings. Fraenkel leaves this regulation to the patient, but warns him against overexertion.

The **advantages of the apparatus** are that it is easily transportable and applicable anywhere (for inducing artificial respiration in cases of chloroform asphyxia, asphyxia of the new-born, poisoning by oxid of carbon, etc.). The apparatus is so cheap that the poorer patients can avail themselves of it and use it at home.

These apparatus are quite easily portable and moderate in price, so

that the patient can have them in his own house and use them as often as may be necessary. It is true that the nature of the materials used in their construction is such that they are easily contaminated, but this is their least objection so far as their efficiency is concerned. The principal objection is the one mentioned by Waldenburg, which is the impossibility of obtaining an absolutely constant pressure, though this objection does not appear to me as vital from a clinical point of view as it did to Waldenburg. It must, nevertheless, be emphasized here.

APPARATUS CONSTRUCTED ON VARIOUS PRINCIPLES

Stoerk's Apparatus.—A number of other apparatus based on different principles have been devised by various authors. Among these Stoerk's apparatus may first be mentioned. The object of this instrument is to enable the subject automatically to inspire condensed air and expire into rarefied air alternately. It is based on the principle of communicating vessels. Instead of compressing the air directly, compression is obtained by a change of level in the water in a system of communicating vessels, brought about by setting up an oscillatory movement which changes their relative positions (Fig. 30). Stoerk's apparatus consists in a bipartite metal receptacle which can readily be disinfected; the two parts communicate through an opening in the lower portion of the partition. One of these portions, destined to receive the air, is closed at the top; the

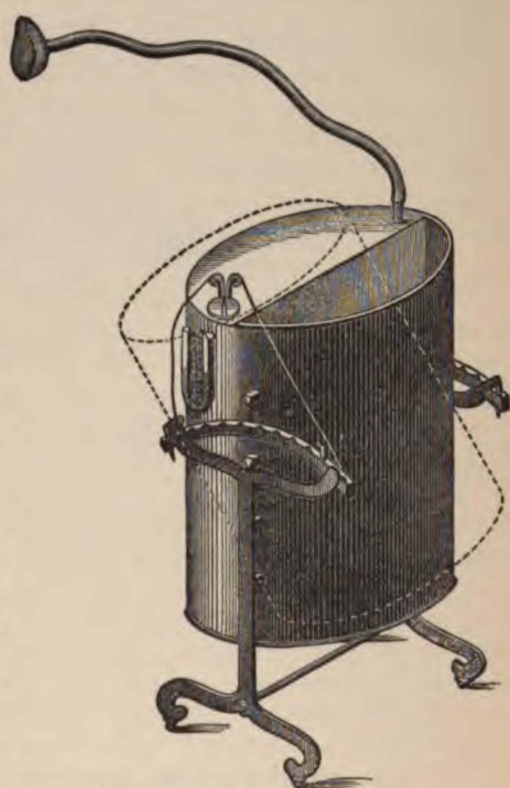

FIG. 30.—STOERK'S APPARATUS.

other, destined to receive water, is open. At the top of the air receptacle is an opening which communicates by means of a tube with a mask that the patient applies to his mouth. The mask is provided with valves permitting either expiration into or inspiration of free air. The entire apparatus is supported on knife-edges like those used in scales, so that it can be readily made to swing backward and forward by pushing it with the hand. The condensation or rarefaction of the air in the receptacle will therefore be in direct proportion to the amplitude of the oscillatory movements. The vessel is half-filled with water and the movements can be regulated at will; for instance, if it is desired, in such a way as to make the backward and forward oscillation coincide respectively with inspiration and expiration; in that case inspiration would be done in condensed and expiration in rarefied air.

Treutler's apparatus is constructed on a similar principle, except that the two vessels are superimposed, one above the other, and communicate by means of a tube. The water, as it flows from the upper to the lower vessel, produces compression of the air in the lower vessel and rarefaction of the air in the upper vessel. This apparatus can be inverted at will. Stoerk's instrument may be compared to the spirometer of Dupont (described in an earlier chapter of this book), which under certain circumstances may be used, with some modifications, as a pneumotherapeutic apparatus; with this apparatus a pressure of 79 to 81 centimeters (30 to 31 inches) of mercury can readily be obtained. It is composed of two graduated vertical rods 1.20 meters (about 4 feet) in length. One of the receptacles of the spirometer can be made to slide up or down these rods at will by means of a rope and pulley and a counterweight; the other receptacle is fixed, and corresponds to a point on the scale between 0.40 meter (15 inches) and 0.80 meter (30 inches). The two receptacles, which are made of glass and have a capacity of 5 liters, communicate by a rubber tube attached to the lower portion of the vessels. The fixed receptacle to which the air has free access may be provided with a Woulff bottle for medicated inhalations. The apparatus is used as follows: The movable receptacle is lowered so that the water from the fixed receptacle flows into it, because the level has been changed. The fixed receptacle is then hermetically closed by means of a rubber stopper perforated by a glass tube, which is also closed at its lower extremity by a stopcock. The movable receptacle is then raised, and as the water tends to flow back toward the fixed receptacle, the air which the latter contains is compressed. The glass tube attached to its upper part is connected by means of a rubber

tube with a mask through which the compressed air can thus be respired.

Berkart's Apparatus.—Berkart, whose principal object was to facilitate expiration, simply had his patients expire into rarefied air for the purpose of diminishing intra-alveolar tension, and incidentally the pressure exerted by the lung on the thoracic wall and the diaphragm (emphysema). The patient's mouth is connected by means of a mask and tube with the cylinder of an aspirating pump. This pump is brought into action at the end of expiration so as to effect a sudden withdrawal of air; this results in a diminution of the residual air in the lungs. The mask and tube are provided with valves that permit the patient to inspire and expire at ordinary pressure until the moment when aspiration is performed. Berkart advised two sittings a day of fifteen minutes each.

Dobell's residual air-pump is quite small (Fig. 31) and the patient can readily carry it in his pocket. It consists of a kind of mask which is

FIG. 31.—DOBELL'S RESIDUAL AIR-PUMP.

fitted to the front of the mouth and held in place with a ribbon which passes around behind the ears; the apparatus is provided with valves to embarrass inspiration while expiration remains free. As a result the intrathoracic air is rarefied, and at the end of three to six respirations the residual air is reduced to a minimum and the diaphragm attains its maximum elevation. The patient then inspires in ordinary air, and this inspiration being freer than he is accustomed to, he experiences a sense of increased comfort. The same manœuver is repeated several times at each sitting. The apparatus is certainly ingenious, but there is no means of determining with accuracy the degree of success attained.

WATER-ENGINE BELLOWS

The Water-blower or Double Ventilator of Geigel and Mayer.—This is constructed on the principle of the water bellows (*Schöpfradgebläse*) and appears to meet all the requirements as laid down by Waldenburg. Its

outward form resembles in a general way that of a gas-meter (Fig. 32); it is composed of an outer envelope of sheet-iron, completely closed except at the top, where it is pierced by four openings. This reservoir contains the water and is filled to about two-thirds of its capacity. In the interior is placed the water bellows, which is worked by a simple mechanism—a crank connected with a cog-wheel placed on the anterior

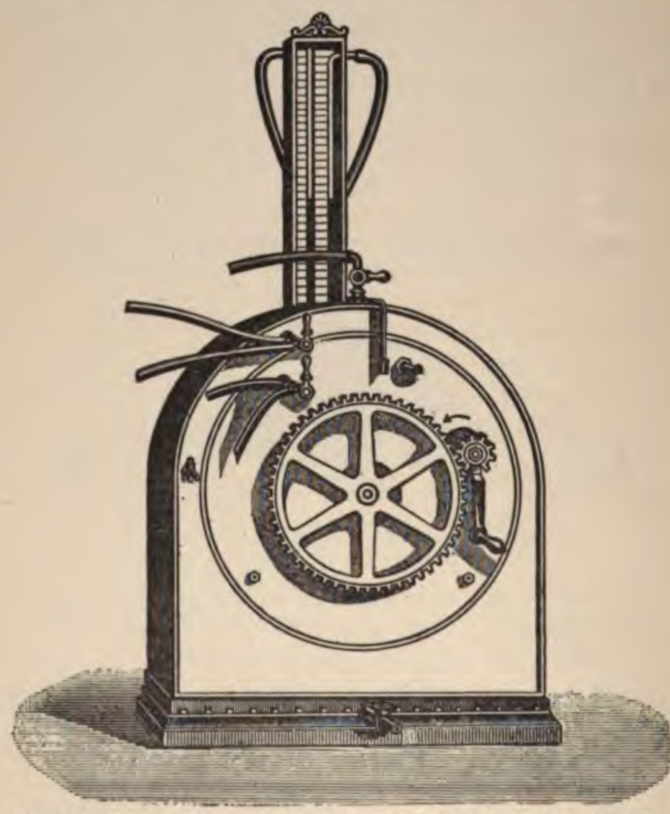

FIG. 32.—DOUBLE VENTILATOR APPARATUS OF GEIGEL AND MAYER.

surface of the apparatus. The concave portion of the wheel is provided with small cells, each of which has a linear opening placed in such a way that when the wheel turns a certain quantity of air, which is originally imprisoned by the pressure of the liquid while the opening is below, escapes when the opening of the cell is directed upward. The air is collected in an inverted reservoir immersed in the liquid; to the top of this reservoir is connected a metal tube which passes through one

of the openings in the upper portion of the apparatus and connects by means of another tube with a mask. One of the other openings in the top of the apparatus communicates with the outside air by means of a tube and stopcock; through the two remaining openings tubes are passed which connect with the two branches of a mercury manometer, and communicate, one with the air reservoir, the other with the upper portion of the outer envelope—also known as the 'mantle'—which is filled with air.

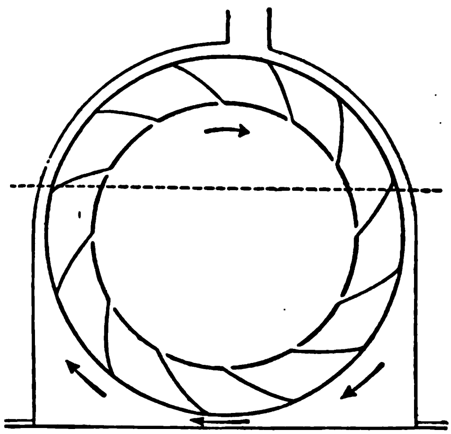

FIG. 33.—SECTIONAL VIEW OF GEIGEL AND MAYER APPARATUS.

Method of Employment.—The machine works as follows: The stopcock that establishes communication between the mantle and the external air being opened, the movement of the wheel draws into the receiver air which, owing to the pressure of the water, is condensed. If it is desired to obtain rarefied air, the stopcock that establishes communication between the mantle and the external air is closed, and the wheel then withdraws part of the rarefied air in the mantle. The same apparatus may therefore be used at will either for condensed or for rarefied air. In general, however, for reasons of convenience, and especially of cleanliness, it is preferable to use two apparatus, one for compression, the other for rarefaction. With this appliance it is possible to obtain a considerable degree of compression or rarefaction, which may be regulated accurately and made to continue as long as is desired. The apparatus has the disadvantage of being very expensive

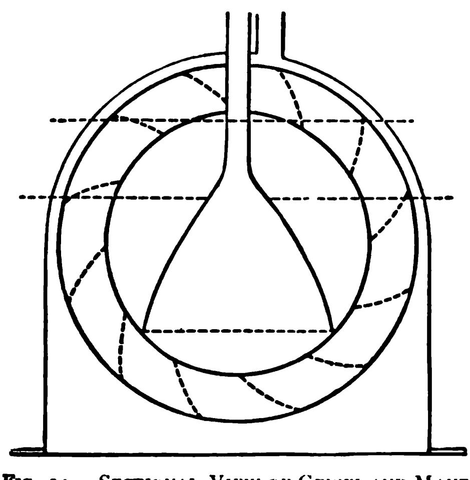

FIG. 34.—SECTIONAL VIEW OF GEIGEL AND MAYER APPARATUS.

and comparatively heavy (300 kilograms, say 600 pounds). Smaller models have been constructed which, however, produce at each revolution of the wheel an augmentation of pressure of $\frac{1}{10}$; nevertheless, by varying the velocity of the revolutions it is possible to obtain a practically constant degree of compression or rarefaction, which may be controlled by examining the manometer.

WATER-PRESSURE APPARATUS

Hogyes's apparatus is based on the principle of Bunsen's water-pump or aspirator. This is perhaps the best apparatus; it is the only one that I have any experience with for rarefied air. It is inexpensive, quite compact, and can readily be set up wherever there is a flow of water. It is possible with this apparatus to obtain a rarefaction, and, if necessary, a compression lasting any desired length of time and practically as high as may be desired. Besides, the desired degree of compression or rarefaction can be obtained equally rapidly and without the slightest fatigue. Hogyes first used this instrument for artificial respiration in animals. For therapeutic use he advises a double apparatus, the one chamber for compression, the other for rarefaction; by means of a mercury manometer the degree of pressure can be regulated at will.

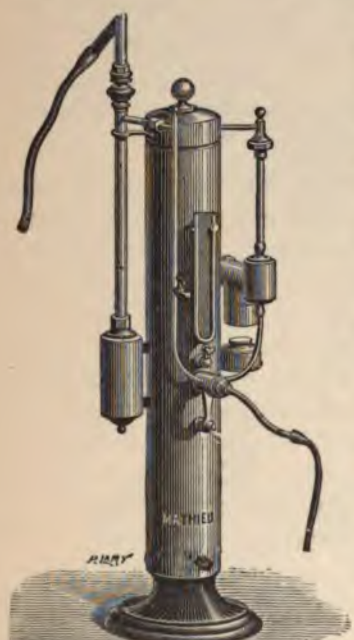

FIG. 35.—DUPONT'S APPARATUS.

Dupont's apparatus, which is commonly used in France, is based on the same principle. It works by means of a water-pressure of about 10 meters. It is composed of a copper cylinder, (Fig. 35) communicating by means of a pipe and a rubber tube with the water-supply. The column of water in the pipe effects aspiration of the external air through a second tube. The air is then drawn into the cylinder, where it is compressed from below upward by the water as the level rises in the lower portion of the cylinder. The compressed air escapes through a pipe leading to the inhalation tube. Behind the instrument is a pipe by

which the water can be drained off, to maintain a constant level. The tubes for rarefied air and for condensed air communicate either with a central two-way stopcock or with two openings in front of which the respiratory tube glides with friction. The latter communicates by a rubber tube with the mask which is applied to the patient's mouth; a third intermediate opening communicates with normal atmosphere. In this way compressed air, rarefied air, or air at atmospheric pressure can be used at will for either of the respiratory phases, or for both; in other words, all possible combinations can be obtained. By means of a manometer the pressure of the rarefied air, or of the condensed air, can be read at any moment. The pressure must not exceed 3 cm. more or less. The pressure may be made to vary either by modifying the flow of water or by working a stopcock placed on the escape tube. There are attachments for heating the inspired air by means of an alcohol lamp and for charging it with medicinal vapors.

COMBINATION OF BELLOWS AND GASOMETER

S. Solis Cohen's Double Apparatus for Home Use.—The combination of bellows and gasometer, simple as it appears, was not made use of prior to the observations of the editor of this series, published in 1883. The apparatus, which is well known in America, deserves to be more extensively used in Europe. It obviates the grave objections that have been mentioned in connection with Waldenburg's and Biedert's models. It is continuous in action and relatively compact; moreover, the price is moderate and it can be used in a patient's home. Nor, although so described by the inventor, is it a mere improvement on Waldenburg's apparatus. It is true that the degree of compression of the air is regulated by means of weights placed on the upper portion of the condensed-air cylinder, and that the degree of rarefaction is regulated by means of weights attached to a system of cords and pulleys by which the cylinder containing the rarefied air is raised; but the apparatus is operated and the pressure modification obtained by means of a double-acting bellows—so that air is drawn out from the cylinder which is to contain rarefied air and discharged into the outer atmosphere, while fresh air is forced into the cylinder intended for condensed air. Although one stroke of the foot-lever accomplishes both condensation and rarefaction, the two systems are independent, and there is no communication between the cylinders except through the air-passages of the patient. This is an extremely ingenious idea, which, in addition to the other good qualities of the

apparatus, should insure its success. It is described by Cohen as follows:

"In 1883, having become convinced, after fair trial of instruments of various mechanical principles, that a combination of the gasometer and

FIG. 36.—S. SOLIS COHEN'S DOUBLE CYLINDER AND BELLOWS APPARATUS FOR HOME USE.

bellows answered best, I constructed, with the assistance of Mr. Charles Richardson, an apparatus of moderate cost for the **inhalation of condensed air.** It was designed especially for use by patients at their own homes, but is also suitable for the physician's office. It is practically a modification of Waldenburg's apparatus; the important improvement

being a reduction in the size of the cylinders, and the use of a foot-bellows to keep up a constant supply of pure air.

"Since first described in the 'New York Medical Journal' for October 18, 1884, the apparatus has been greatly improved. As now constructed (Fig. 36) the air-chamber is eight inches in diameter and twenty-four inches high. The water-chamber is pierced at the level of the base of the overflow tank (seven inches from the top) with a row of perforations, allowing the water to escape into the tank under pressure of air in the air-cylinder. A glass tube connected with the tank shows the level of the water therein, and by means of a scale painted on the outer surface of the tank acts likewise as a gage indicating the pressure. The air-cylinder carries, two inches from its open base, two shelves, one on each side, on which are placed ballast-weights for the purpose of lowering the center of gravity and thus maintaining the steadiness of the apparatus. Both shelves and weights are perforated to avoid undue resistance of water. As the area at the top of the air-chamber is just fifty square inches, atmospheric pressure upon it equals, in round numbers, seven hundred and fifty pounds. With the ballast upon its shelves the cylinder weighs ten pounds, giving an excess pressure of $\frac{1}{75}$ atmosphere. Weights are furnished in two sizes in the shape of rectangular blocks of iron about $4\frac{1}{2}$ inches by 2 inches surface, and about $\frac{1}{2}$ inch thick and 1 inch thick, respectively. The smaller ones are bored out to weigh $1\frac{1}{4}$ pounds each; the larger ones to weigh $2\frac{1}{2}$ pounds each.

"Being placed on top of the air-chamber in successive pairs (one on each side, to preserve balance), they bring the pressure up to any desired amount not exceeding + $\frac{1}{30}$ atmosphere. Thus:

Cylinder and bottom weights	= 10 lbs.	= + $\frac{1}{75}$	atmosphere.
$2\frac{1}{2}$ lbs. (two small weights) additional	= $12\frac{1}{2}$ lbs.	= + $\frac{1}{60}$	atmosphere.
$2\frac{1}{2}$ lbs. (two small weights) additional	= 15 lbs.	= + $\frac{1}{50}$	atmosphere.
$3\frac{3}{4}$ lbs. (one small weight and one large weight) additional	= $18\frac{3}{4}$ lbs.	= + $\frac{1}{40}$	atmosphere.
$6\frac{1}{4}$ lbs. (one small weight and two large weights) additional	= 25 lbs.	= + $\frac{1}{30}$	atmosphere.

"The air-cylinder was originally furnished with two goosenecks, one for the attachment of the tube from the bellows, conveying condensed air; the other for attachment of the tube connected with the stopcock and face-mask or mouthpiece, through which the patient inhales. In the improved apparatus air enters through a large internal pipe fitted with a valve and extending below the stand, where it is connected with a 1-inch hose from the bellows. A single gooseneck above serves for the attachment of the tube leading to the stopcock and mask. A perforation two inches in diameter

is fitted with a screw-cap carrying a hook on which may be placed a sponge saturated with any volatile medicament (*e. g.*, terebene) that may be desired. The cap likewise contains a smaller perforation, into which a manometer may be fitted. When the gage is not in use, this is closed with a rubber plug. Still another perforation in the top of the air-chamber is fitted with a valve that permits escape of air should too much be sent over from the bellows. The escape-valve is composed of two flat plates of brass, the upper perforated, the lower unperforated. They are held in apposition by a spring, and when in apposition no air escapes. The lower plate carries a chain thirty-five inches long, to which is attached a weight that rests upon the floor of the water-chamber. Should too much air enter the cylinder, lifting it too high, the plates are pulled apart, the air escapes through the perforated plate, and the cylinder falls to the proper level. This obviates any liability to splashing of water, which before this attachment was made would occur if attention were not paid to a line painted on the cylinder to indicate cessation of pumping. By means of the automatic escape-valve we are enabled to introduce a continuously acting pump if desired. As an additional precaution against splashing, the air-chamber and overflow tank are each provided with a deflecting hood about an inch and a half wide and inclined at an angle of forty-five degrees.

"Later, a second gasometer was added for **expiration into rarefied air.** The connection with the bellows is reversed, so that the latter takes air from the gasometer and delivers it into the room or the street; and the air-chamber is suspended from a small pulley and counterpoised with weights varied according to the desired negative pressure. The mechanical arrangement of pulleys and weights, the devices for adjusting the weights, the lowering of the outer water-tank (now a reservoir, and not for overflow), the opening of the automatic governing valve for admission of air, etc., are so obvious and so easily understood by looking at the figure that description in detail is unnecessary. A wire rope is used in preference to one of hemp.

"The combination of the two gasometers into one instrument is effected by means of a bellows which at the same stroke condenses air for delivery into one cylinder and rarefies air in order to exhaust the other cylinder. It is in reality two bellows, mounted back to back on the same frame. The downward stroke of the lever compresses the lower bellows and expands the upper one. The recoil of the spring in the lower bellows expands that one and compresses the other. There is no communication between the two bellows. By means of a tube passing out of a window-board—the external opening being protected with wire gauze—

the supply of air for inhalation is drawn from out-of-doors; and a similar attachment discharges the air of exhalation.

"The condensed-air cylinder is intended for inspiration only; the rarefied-air cylinder for expiration only; they may be used separately or together. When both cylinders are used together, being brought into communication through the lungs of a patient by means of a double stopcock connected with the face-mask or mouthpiece, the route for the air is as follows: (*a*) From the street, (*b*) through the upper bellows, (*c*) to the compression gasometer, (*d*) thence to the lungs; (*e*) from the lungs, (*f*) through the rarefaction gasometer, (*g*) to the lower bellows, (*h*) which expels it into the room or into the street. The compression and rarefaction are virtually made in the respective bellows. The gasometers act to a certain extent as reservoirs, but chiefly as intermediate regulating chambers, rising and falling to maintain a constant pressure in exact accordance with the weight placed upon them, and independent of the volume of air inhaled or exhaled. Their available capacity is a little more than eight hundred cubic inches. If it be desired to have continuous respiration of either condensed or rarefied air, one of the cylinders is detached from the mouthpiece, and a **resistance valve** (see page 228) substituted. For condensed air, the inhalation cylinder and expiration valve—for rarefied air, the inspiration valve and exhalation cylinder—are used.

"The air-chambers carry a scale of cubic inches, enabling one to see the approximate volume of air inhaled or exhaled at each respiration. This is sufficiently accurate for clinical comparisons, though not for physiologic data. Apparatus for filtering, warming, chilling, drying, moistening, or medicating the air to be inhaled may be interposed at any point between the window and the patient. The illustration shows **a filter** consisting of a glass globe containing cotton, between the bellows and cylinder. The most convenient method of **medicating** the air is by means of the sponge, as described. A variety of other methods is applicable. Thus a volatile medicament may be placed in or on the water contained in a Woulff bottle, through which the air is passed; or the spray from Oliver's nebulizer may be thrown into the inspiratory current.

"If a pump and motor are substituted for the foot-bellows, the only inconvenience connected with office use of the apparatus can be obviated. The additional cost is not excessive, and it leaves the apparatus still well within the price of any other capable of doing the same work."

Cohen's Apparatus for Use in Hospital

"For the proper utilization, according to the differential method, of

the therapeutic properties of condensed and rarefied air in hospitals or institutions where a large number of patients are to be treated, it is desirable that there should be constructed at moderate cost an apparatus with which several patients may be treated at one time, but that will

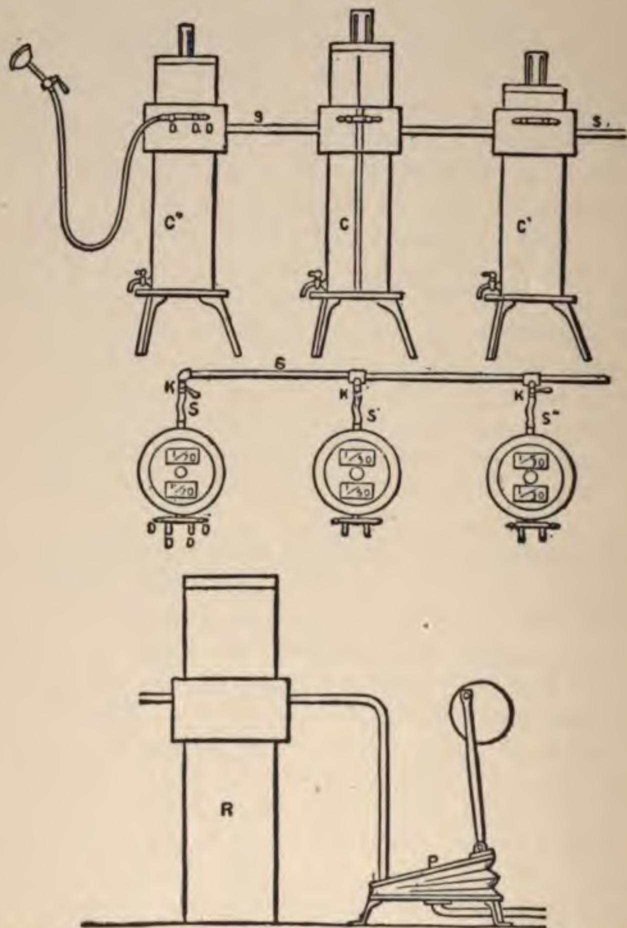

FIG. 37.—COHEN'S PNEUMATIC APPARATUS FOR HOSPITALS.

nevertheless permit of accurate adjustment of pressure to the varying necessities of different individuals.

"The preceding sketch is for an apparatus for compressed air to treat twelve patients at once (Fig. 37). As each patient inhales but ten to fifteen minutes, and then rests for the same period before inhaling for

the second time, seventy-two patients could be treated during two hours with this size of apparatus; so that it would be quite large enough for most institutions. It would be used, say, for fifty or sixty patients about three to four hours daily, as most patients would require two sets of inhalations—one in the morning and one in the afternoon. It could thus be run, say, from 9 to 11 A. M. and from 3 to 5 P. M.

"C, C′, C″ are gasometers slightly modified from Waldenburg's—such, indeed, as employed in the home apparatus just described—except that, instead of being fitted with but one delivery-tube, each has four delivery-tubes, D, D, D, D, and the size of the cylinder is correspondingly increased. C is weighted at the bottom for a pressure of $+\frac{1}{80}$ of an atmosphere, and additional weights may be placed on top to bring the pressure up to $+\frac{1}{70}$ of an atmosphere. C′ is weighted for $+\frac{1}{60}$ atmosphere, and the pressure may be increased to $+\frac{1}{50}$ atmosphere. C″ is weighted to $+\frac{1}{40}$ atmosphere, and the pressure may be increased to $+\frac{1}{30}$ atmosphere. S is a supply-tube with branches, S′, S″, S, leading to a reservoir, R, into which air is pumped from the outside atmosphere (pure air) by a pump or bellows run by an electric motor or any other source of power. The power required will be between one-quarter and one-half horse-power. This reservoir is weighted to give an air-pressure greater than any used in the cylinders, C, C′, C″, and will always force air into them. The reservoir can be so adjusted that when full it will automatically stop the pump or bellows, either by opening a switch, if an electro-motor be used, or by interrupting the mechanical connection if the source of power be a steam-engine or other motor. Valves in each of the cylinders, C, C′, C″, controlling the connection between R and the gasometers, are so arranged as to regulate automatically the ingress of compressed air into the latter; so that when the air-cylinders have fallen to the lowest point the valves are open to their full extent, and, as the cylinders rise and reach the proper point, the valves are closed and the air-supply cut off. When a gasometer is not in use the air-supply is cut off by the stopcock K. Attachments for filtering, warming, cooling, drying, or moistening the air may be placed at any desired point between the outer atmosphere and the patient. The gasometers have hook and sponge attachment for volatile medicaments; or when special medication for the individual patient is desired, any appropriate medicating apparatus may be interposed between the gasometer and the mask covering the patient's face. As many gasometers as may be desired may be brought into communication with the reservoir, and, if necessary, any increased number of delivery-tubes for patients may be connected with each gasometer.

The gasometers may be arranged for any fixed or adjustable pressure desired. Necessarily, all the patients using the same gasometer at the same time will inhale air at the same pressure. It is believed that the arrangement of pressures here suggested will meet ordinary requirements among the number of patients for which the apparatus is calculated. Patients beginning treatment would require from $+\frac{1}{80}$ to $+\frac{1}{70}$; those who had become accustomed to it would need from $+\frac{1}{60}$ to $+\frac{1}{40}$; exceptional cases would be benefited by $+\frac{1}{30}$. Should a fourth cylinder be introduced, it might be permanently weighted for $+\frac{1}{60}$ and furnished with additional weights up to $+\frac{1}{30}$; although, as in the ordinary apparatus for home and office use, each cylinder may be permanently weighted to $+\frac{1}{75}$ only, and furnished with weights up to $+\frac{1}{30}$. The sketch merely gives a general plan, capable of modification as required.

To supply three gasometers in constant use by twelve patients, estimating that the patients average ten respirations each in the minute, and inhale on the average 200 cubic inches (3280 cubic centimeters) of air each at each inspiration,—*i. e.*, that from the three gasometers 24,000 cubic inches (393.6 liters) of air are delivered in a minute, at an average excess pressure of $\frac{1}{60}$ of an atmosphere, equal to 24,400 cubic inches (400 liters) at ordinary pressure,—the reservoir, R, would not have to be larger than about 12 inches in diameter and 36 inches in height. Any form of bellows or pump that will give sufficient air can be used with this apparatus. If desired, apparatus for expiration into rarefied air may be combined with this. As it is not wise to exhale into the same cylinder from which inhalation is made, separate gasometers, counterpoised, should be provided for the purpose, and connected with a large reservoir and pump. The pump would be supplied from the reservoir and discharge into the outer air.

INTERNAL RESPIRATORY DIFFERENTIATION

Instead of modifying the outer air, we may, for certain purposes, effect by mechanical means changes of pressure in the air that is **within the respiratory tract.** This may be accomplished with or without apparatus.

Internal Respiratory Differentiation without Apparatus

By means of certain manœuvers an increase or a diminution of the pressure of the air contained in the respiratory passages may be brought about at will without the aid of instruments.

Valsalva's experiment is utilized to **raise the intrathoracic pressure.** It puts into systematic operation the physiologic phenomenon of muscular effort, as habitually made, or with slight modifications. Full inspiration is followed by a vigorous expiratory effort in which all the ordinary, as well as the accessory, muscles of respiration are called into play. At the same time that the expiratory effort is made, the air is **prevented from escaping** (*a*) by simple closure of the glottis (phonal resistance); or (*b*) by closing the mouth, the nasopharynx being at the same time shut off from the oral cavity by the soft palate (oro-palatal resistance); or (*c*) by closing both the mouth and the nostrils (oro-nasal resistance). To diminish the effect, the lips may be parted slightly, or the finger may be lifted from one nostril, or from both nostrils at the same time.

The oro-nasal method is the one most often described as Valsalva's experiment, and, aside from the effects on respiration and circulation,—which are the same as with the other two methods,—has a special action upon the **ears.** When the expired air attains a pressure equivalent to from 20 to 60 millimeters of mercury, it forces itself through the Eustachian tubes into the tympanum with a peculiar crackling sound which the patient himself perceives and which can be heard with an otoscope. Inspection with the aid of a speculum at the same time reveals bulging of the drumhead. This penetration of air into the middle ear does not take place in the presence of pharyngeal lesions obstructing the tubes. The procedure, which patients often resort to of their own accord in deafness from recent obstruction of the Eustachian tube, is **indicated** in all cases in which it is desirable to obtain an effect upon the mobility of the ossicles; its **drawback** is the production of venous congestion in the tympanic cavity which may, in the long run, be the source of trouble. In cases of acute disease of the pharynx Valsalva's experiment may be the means of carrying pathogenic organisms into the middle ear. The effects of Valsalva's experiment on the ear will be dismissed with this brief reference, as it is not the province of this work to discuss the subject from an otologic standpoint. It will be more profitable to study the effects of the procedure on respiration and circulation; which will also enable us to understand more readily the effects of differential apparatus.

Immediate Effects of Valsalva's Experiment.—Intrathoracic air-pressure is markedly elevated. In consequence the pulmonary alveoli are distended and portions of lung tissue are called into play which normally do not functionate actively. The pressure exerted by the condensed air tends to enlarge the elastic walls of the thorax, the costal, and especially the diaphragmatic wall. The air is thus brought in contact

with the alveolar epithelium over an increased surface, so that it might be supposed that the respiratory exchanges would become more active. Daily experience, however, shows that this is not the case, and the reason is to be found in the effects of intrathoracic air-pressure upon the vessels and upon the heart. The pulmonary capillaries and veins are diminished in volume, and the passage of blood through the arteries is therefore impeded. Hence there is produced a relative anemia of the lungs which explains the fact that there is no augmentation of respiratory gaseous interchange. In addition, the increase of intrathoracic pressure shows its effect upon the heart, embarrassing diastole at the same time that it facilitates systole. The constraint upon the pulmonary circulation and upon cardiac diastole has been taken to explain the venous stasis and the diminution of arterial pressure observed in the general circulation. Lazarus pointed out that in consequence of the depression of the diaphragm, and, it may be added, the contraction of the abdominal muscles of expiration, the abdominal cavity also becomes the seat of increased pressure, which is another factor in the production of peripheral venous stasis. It is probably not the main factor, however. The chief cause is rather to be sought in the effect of increased intrathoracic pressure on the right auricle and on the venæ cavæ; which also explains the intensity of the stasis in the veins of the neck and head.

Remote Effects of Valsalva's Experiment.—The available respiratory surface and the capacity of the thorax are enlarged; the elasticity of the thoracic walls is increased, and, in consequence, more active pulmonary ventilation and respiratory interchange are brought about. Accordingly, Rossbach has maintained, what might almost appear to be an amusing paradox, that infants should be allowed to cry freely. The new-born child, practically incapable of any other effort than that of crying, thus automatically indulges in respiratory gymnastics. Those mothers who hush their noisy infants and try to accustom them never to cry, risk seeing them grow up with a poor thoracic development and with a predisposition to tuberculosis. Rossbach's authority is our excuse for mentioning this opinion, and we have done so without forgetting that exaggeration may injure the acceptance of the greatest truth.

Müller's experiment is employed to **diminish intrathoracic pressure.** The lungs are emptied by a vigorous expiratory effort; all the muscles of inspiration are then called into action, while at the same time the mouth and nostrils are held shut—or to lessen the effect, one of the nostrils may be left open. The procedure causes a rarefaction of the air in the respiratory passages—an increase of the negative intrathoracic

pressure, and a greater flow of blood into the pulmonary vessels and into the venæ cavæ. Cardiac diastole is facilitated by the direct effect upon the heart of the lowering of intrathoracic pressure. It is evident that under these conditions the quantity of blood in the veins of the greater circulation is diminished. As to the **effect upon arterial pressure,** it is a remarkable fact that authorities do not agree. While Knoll noted a marked increase in arterial pressure with the first normal inspiration following Müller's experiment, Waldenburg arrived at the opposite conclusion. It may be noted, in advance of our discussion of **external mechanical pressure methods,** that the effect of Valsalva's experiment is increased by external pressure on the chest and abdomen. This procedure, which is known as **Weber's experiment,** may be employed as a partial substitute for expiration into condensed air. In **Gerhardt's procedure,** on the other hand, expiration is **assisted** by compression of the chest and abdomen. It has in part the effect of expiration into rarefied air.

A serious **drawback** to the employment of both Valsalva's and Müller's experiments is the impossibility of graduating the effect upon the lungs, and more especially upon the heart. This is overcome by the use of the resistance valves of S. Solis Cohen, to be described later.

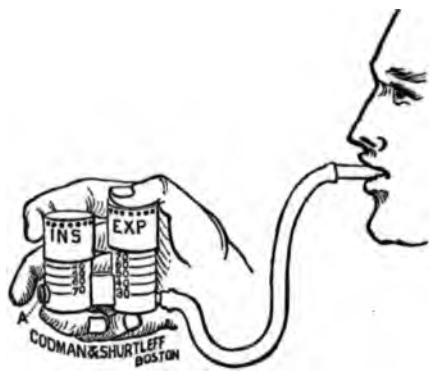

FIG. 38.—S. S. COHEN'S RESISTANCE VALVES.

Internal Respiratory Differentiation by Means of Resisting Apparatus

Dobell's residual air-pump has been described on page 213.

Cohen's resistance valves are little cylinders containing ebonite valves controlled by spiral springs (Fig. 38). The tension of the spring is regulated by turning the cap of the cylinder, and a scale engraved upon the side gives its value in fractions of an atmosphere. The **expiration valve** is arranged to move **toward** the perforated distal end of the cylinder, thus allowing the expiration current to escape whenever the pressure of the expired air reaches the indicated figure. The valve of the **inspiration cylinder** is arranged to move **from** the perforated top of the cylinder, thus allowing the inspiration current to pass toward the patient whenever the rarefaction within the lung reaches the indicated figure.

Either valve may be inserted into the stopcock connected with a gasometer apparatus for differential pressure, or the two valves, suitably mounted in one instrument, may be used independently, to oppose by a known pressure both or either of the phases of respiration. The exact regulation of pressure is their peculiarity and chief merit. They are simply a better instrument than the tube (five feet long and one-half inch in diameter with narrowed extremities) used by Ramadge, and effect the same purpose that this pioneer in aërotherapy aimed at: namely, hyperdistention of the pulmonary alveoli through (*a*) increased muscular respiratory effort; (*b*) prolongation of the time of both phases of respiration; and (*c*) backward pressure of contained air during expiration. Their greatest usefulness in this way is as a means of **regulated pulmonary gymnastics,** either to keep up the good effects of treatment with the gasometer methods, or in **prophylaxis** before resort to the gasometer has become necessary.

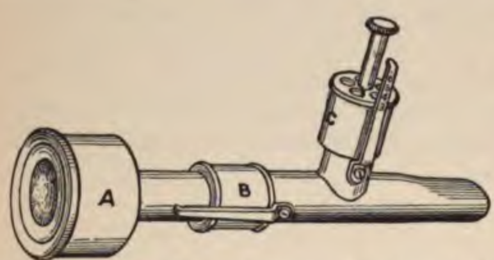

FIG. 39.—S. S. COHEN'S SIMPLIFIED RESISTANCE VALVES.

A, Receptacle for medicated cotton; B, inspiration valve; C, expiration valve.

Another form of pneumatic resistance valves by the same author—to which he has added a chamber for medication of the inspired air—is shown in the accompanying cut (Fig. 39). It is less accurate, but also much less expensive than the original model, and serves as well for all ordinary therapeutic purposes. The inspiratory valve (B) is that nearest the inhalant chamber; the expiratory valve (C) that next the lips while inhaling. The inhalant chamber (A) contains a sponge or tuft of absorbent cotton, which may be saturated with some medicinal substance. The **resistance** of the valves is greatest when the cylinders are closed and their milled edges are opposite the degree indicated by 3, corresponding to about $\frac{1}{30}$ of an atmosphere or one-half pound. The resistance is diminished by turning the cylinders to the left, to unscrew them.

With Cohen's double bellows apparatus and a pair of resistance valves it is possible to obtain the mechanical satisfaction of all the conditions required for any of the therapeutic expedients mentioned on page 195.

Ramadge's Tubes.—Ramadge had his patients breathe the emanations from heated tar through long narrow tubes, the diameters varying with

the ages of the patients, and attributed all the benefits derived from the inhalation to this respiratory exercise of the lungs. The length of the tube serves the double purpose of protecting the patient's face from the heat of the inhaling apparatus, and of retarding the free egress of air from the lungs, which is an essential feature of a perfect inhaler.

In the short tube now known as Ramadge's, or sometimes as Howe's (Fig. 40), a pea-valve acts as an obstruction to the current of respiration; similarly in a number of other devices, known as **breathing tubes,** Evans's, Denison's (resistance inhaler), and others,—even one sold under a proprietary name as a cure-all,—resistance is effected without measurement, by plate-, bulb,- or T-valves, or by placing a finger over a small hole in the tube. These appliances are good in general principle, but as the regulation of pressure is impossible, they must be regarded as unscientific. Except for psychic effect—and this is not to be disregarded—they achieve no more than breathing exercises with slightly parted lips.

FIG. 40.—HOWE'S BREATHING TUBE.

Spirometers may be used in the same way as Cohen's resistance valves, or the ordinary breathing tubes, over which they offer no special physical advantage. Psychically, they have the suggestive merit that the patient's interest in the exercises is stimulated from day to day by the fact that he is able to note the progressive increase in his respiratory capacity. The instruments, of which there are a number of models on the market (Fig. 41 and Fig. 42), require no special description. Their effects are like Valsalva's experiment, and the benefit consists in strengthening the muscles of expiration and causing hyperdistention of the pulmonary alveoli by backward pressure.

FIG. 41.—RESISTANCE SPIROMETER.

Direct Hyperdistention of the Pulmonary Alveoli.—This is accomplished by a simple procedure devised by Dr. W. Y. Gadbury, of Mississippi, for the inhalation of compressed air. The patient, after dilating the lungs to their greatest capacity by a forced voluntary inspiration, immediately compresses the nares with one hand, while with the other

he places between his lips the tube of an ordinary rubber compressor (atomizer bulb), and then rapidly works the compressor. As soon as the distention becomes unpleasant or the need of an expiratory movement is felt, the instrument is withdrawn, to be replaced and again employed in the same manner a few moments later. The procedure is then to be repeated four or five times in succession. It may be combined with inhalation of volatile medicaments or nebulized liquids by placing between the lips or into the nostrils the delivery-tube of an Oliver's nebulizer or one of its numerous modifications—as Evans's or Pynchon's, for example—and operating the nebulizer either by a bulb, a pump, or condensed air from a reservoir. (See part II, Inhalation Therapy.)

FIG. 42.—SPIROMETER USED FOR RESISTANCE EXERCISES.

J. Solis-Cohen recommends this procedure principally as a **mechanical expectorant.** In this way it may be used with advantage by the patient at home, in **chronic bronchitis** and in the **cough of phthisis.** It also furnishes a convenient method of clearing the air-passages preparatory to a physical examination. The **physical action** of this mechanical expectorant is as follows: The hyperdistention of the air-vesicles permits the access of air under pressure to points beside and beyond the masses of mucus clinging to the walls of the bronchioles and alveoli, and excites effective cough which removes the partially detached masses.

EXTERNAL DIFFERENTIAL PRESSURE METHODS

Various methods have been devised to **assist the motion** of the chest-wall and thus facilitate expiration or inspiration; also for the modification of circulation, local or general, respiratory or peripheral. **Manual compression,** compression of the thorax by **immersion,** and **mechanical procedures** will be described in connection with exercise; here I shall mention the **external** (partial or general) **application of**

condensed or rarefied air to the body, as in the tub of Hauke, the cabinet of Williams and Ketcham, Junod's boot, and the like.

Hauke's Pneumatic Cabinet.—Hauke suggested the use of a **cuirass,** and of a **pneumatic tub** (Fig. 43) constructed upon the same principle. He soon abandoned the cuirass in favor of the **pneumatic box** or **cabinet,** which is so constructed that the patient introduces the entire body with the exception of the head, and therefore breathes air under ordinary pressure. The cabinet communicates with two reservoirs, one containing condensed, the other rarefied air. During inspiration the air in the cabinet is rarefied, and expansion of the chest is facilitated. During expiration the air in the cabinet is condensed, the result of which is to aid thoracic retraction and render it more vigorous. By this means the two phases of respiration are influenced, and in an absolutely mechanical manner. The procedure may be truly said

FIG. 43.—HAUKE'S PNEUMATIC TUB.

to be a method of artificial respiration. Hauke recommends his apparatus especially for children, who generally refuse to breathe into the so-called portable appliances, and, in fact, experience great difficulty in doing so. He has used it successfully in a variety of cases. Kaulich has also obtained good results.

Pneumatic Cabinet of Williams and Ketcham.—Dr. H. F. Williams, of Brooklyn, New York, with the aid of Mr. Ketcham, of the same city, devised in 1885 an air-tight cabinet in which, by means of a large bellows, the air can either be alternately condensed and rarefied, or subjected to continuous condensation or rarefaction, while the patient seated within the apparatus breathes atmospheric air through a tube that pierces the side of the cabinet. Theoretically any desired modification of the pressure on the external surface of the body can

thus be brought about, the attendant operating the bellows synchronously with the patient's respiratory movements. Various attachments permit **medication** of the inspired air with vapors, sprays, or nebulæ, or the introduction of **resistance valves** in the path of the respired air. The inventors contend that in thus modifying the *vis a fronte* by increasing or diminishing the external pressure on the thorax, better results are achieved than with apparatus of the Waldenburg type; in reality, however, while the psychic effect of the cabinet is probably better than that of the cylinders, there is no physical or physiologic difference between the action of the two types of apparatus—the therapeutic modifications of pressure being well within the limits of ordinary barometric fluctuations. In actual practice, moreover, perfect synchronicity between the action of the bellows and the patient's thoracic movements cannot be maintained, and the cabinet is used for **continuous condensation or rarefaction,** so that the effect is virtually the same as if the patient were made to continuously respire condensed or rarefied air. The apparatus is not readily portable, and it is relatively expensive. A great debt, however, is due Dr. Williams for aiding to popularize among the physicians of the United States the knowledge and practice of pneumatic differentiation as a therapeutic measure—this phrase, indeed, seems to have been employed first in his writings. Competent observers have reported excellent clinical results from the use of his pneumatic cabinet, especially in cases of **pulmonary tuberculosis.**

LOCAL APPLICATIONS OF AIR-PRESSURE

The **general effect of air on the skin** has been little exploited for therapeutic purposes. The modifications produced in the skin by condensed- and rarefied-air baths have been referred to in connection with the absolute pressure methods.

Local applications are much more commonly used. They consist sometimes of an **increase in pressure,** as in massage by means of a jet of condensed air; insufflation of the middle ear by the methods of Valsalva and Politzer; and direct or indirect insufflation in asphyxia neonatorum (see page 280). Sometimes a sudden **diminution in pressure** is utilized, as in ordinary cupping, in cupping with Junod's boot, in procedures involving rarefaction of the air in the external auditory canal, and in the use of artificial nipples.

A few lines may be devoted to a discussion of these procedures, or at least a few of them. The artificial nipple, the ordinary cup,

and the technic of insufflation of the middle ear have become matters of general knowledge and practice.

Cupping

In cupping, the tissues underneath are literally pushed into the cup by a *vis a tergo*, which is nothing but external (atmospheric) pressure. The congestion of the dilated blood-vessels slavishly obeys the laws of hydrostatics; the swelling of the tissues and the accumulation of blood are limited only by the elasticity of the vessel-walls and by the resistance of the tissues that protect them. The slightest laceration of the integument suffices to allow the escape of streams of blood under a pressure directly proportionate to the previous degree of rarefaction. By increasing the working surface of the cup, and transforming it into a pewter receptacle capable of inclosing an entire extremity or even the entire body, Junod was able to obtain very intense therapeutic effects.

Junod's Boot.—There is no doubt that this instrument has fallen into unmerited disrepute at the present time. It consists of a pewter cylinder of varying size, depending on whether it is to be used on the upper or on the lower extremity. The upper end of the tube is provided with a cuff of rubber which makes it possible to obtain a hermetic joint. To the pewter cylinder is attached a tube armed with a stopcock through which the air can be rarefied to any desired degree by means of an air-pump. Junod, by filling the cavity of one of his leg-cups or *meroscéliques* with tepid water before and after applying it to the body, demonstrated that a single application displaced in as gradual a manner as possible a quantity of blood equal to 1700 liters. An apparatus similar to that designed by Junod is used to demonstrate that the action of the cup is due not to an active sucking force by the negative pressure of the air in the apparatus, but solely to a passive impulse on the part of the blood, which is propelled from the areas of greatest pressure toward the point where the pressure is diminished. The difference in pressure is the sole factor concerned, whatever may be the absolute values. Even when air is compressed in a large apparatus resembling that of Junod, but including the entire body with the exception of a single member, a swelling will take place in the excluded member exactly similar to that which would be produced by the rarefaction of air in a cuff surrounding only the member in question and leaving the rest of the body free.* An analogous cause

* Much of the above is quoted directly from Guebhard.

is assigned by Marey for the hemorrhages from the middle ear and from the lungs which are occasionally observed in naked divers. If we consider the lungs, for example, what conditions do we find? The glottis closes to prevent the entrance of water into the respiratory passages and at the same time imprisons a volume of air in the thoracic cavity which is under the same pressure as the atmosphere. When the individual dives, the pressure may reach 1½, 2, or even 4 atmospheres. This pressure is transmitted in every direction and becomes neutralized everywhere except in the lungs, which are protected by the thoracic cage. Hence an effusion of blood takes place into the vessels of the lungs, the distention becomes extreme, until the volume of gas is diminished and an equalization of pressure is achieved. If the elasticity of the pulmonary vessels is inadequate to the strain, rupture necessarily results.

CHAPTER VII

PHYSIOLOGIC EFFECTS AND THERAPEUTIC USES OF DIFFERENTIAL PRESSURE METHODS

Effect on the Respiratory Apparatus; Effect on the Circulatory Apparatus; Effect on the Nutrition. Therapeutic Application of Differential Methods: —Diseases of the Respiratory Apparatus—Affections of the Upper Air-passages; Bronchial Affections; Diseases of the Lungs—Emphysema, Asthma; Diseases of the Pleura—Scrofibrinous Effusions, Empyema, Adhesions; Pulmonary Tuberculosis; Counterindications. Diseases of the Circulatory Apparatus—Cardiac Affections, Counterindications; Peripheral Action; Hypotension, Phthisical Habitus; Counterindications.

PHYSIOLOGIC EFFECTS OF DIFFERENTIAL PRESSURE METHODS

Summary

The so-called portable or differential pressure apparatus, which have been described at some length, after having for a number of years enjoyed considerable popularity, have now fallen into somewhat unmerited neglect. The opinion current in Germany and France that this therapeutic method, as such, is altogether valueless should not be accepted without a vigorous protest. If it were true that it represents nothing but a form of pulmonary gymnastics, and that the numerous apparatus designed by different authors are mere scientific toys, calculated by their very complexity to impress the imagination of patients and thus to produce the same effect as any other form of suggestion, the present chapter would have been suppressed in a book whose object is not to display the writer's knowledge of scientific literature, but to serve as a practical guide in therapeutics.

Medical errors, of which even the twentieth century is already quite prolific, should be accorded a certain measure of indulgence; and the best way to show such indulgence in many instances is to pass the errors over in silence. This, however, is not the case with regard to the present question, and it seems profitable to investigate the causes of the profound reaction that characterizes contemporary views in regard to

many therapeutic methods that at first sight appear to be based on sound scientific principles.

It is but just to say that Waldenburg, the foremost worker in the field of active respiratory exercises performed with so-called portable apparatus, is responsible both for the initial enthusiasm and for the subsequent reaction in regard to pneumotherapeutic methods. It is the dream of all therapeutists, as it is the aim of many laboratory workers at the present day, to elevate medicine to the rank of an exact science with immutable laws and principles. But the dream is very far from realization. We are not yet justified in deducing *à priori* from our exact knowledge of the action of a therapeutic agent its effect in a given case of disease. In practice, experience goes before theory. Waldenburg determined with what he thought was mathematical precision the effects of pneumotherapeutic apparatus on the lungs and on the circulation, and laid it down as a principle that these effects must be produced in every case. "Just as the application of cold always results in cooling, so an increase of pressure in a cavity with elastic walls must always produce distention, and a diminution of pressure bring about retraction of the walls of the cavity. There is an immutable physical law to which organic as well as inorganic bodies are subject, and in this case the ultimate result cannot be averted either by the nerves or by the blood-vessels. If a vessel containing air under a certain pressure is connected by a system of tubes with another vessel the walls of which are elastic, the pressure in the two vessels will become equalized so soon as communication has been established; the pressure in the elastic vessel will be augmented or diminished according as the original pressure in the vessel with rigid walls is greater or less than the original pressure in the elastic vessel. The latter will expand or retract in proportion to the difference in pressure and the elasticity of the walls." Thus wrote Waldenburg; but as a matter of fact it is a question of physiology, not of physics. Granted that the thoracic cage is comparable to the vessel with elastic walls, it must not be forgotten that the organism, in this as in every other case, possesses the power of accommodating itself to the new conditions to which it is subjected; and Waldenburg was mistaken in denying the influence of nervous, neuro-muscular, and vasomotor processes. On the contrary, the effort on the part of the organism, when suddenly placed under unusual conditions, to call these protective agencies into action, has been considered by many authors to be chiefly responsible for the main physiologic effects produced by the active (or differential) pneumotherapeutic methods. It is probably along these lines that the most satisfactory

explanation for many of the therapeutic results obtained will be found, although I believe that in the majority of instances the results must be ascribed to purely mechanical causes.

Following the example of Knauthe, Sommerbrodt, and others, it will be necessary to pass in review the mechanical, chemical, and neuro-reflex effects of the differential method of pneumotherapy, although it is of course physically impossible to review the entire literature on the subject, which is still far from being concluded. First, the conclusions formulated by Waldenburg and the criticisms which they have provoked will be summarized.

I. EFFECT ON THE RESPIRATORY APPARATUS

Waldenburg's conclusions are as follow:

(A) **Inspiration of Compressed Air.**—The general effect is that of a true **inflation of the lungs.** With an excess pressure of $\frac{1}{40}$ to $\frac{1}{80}$ of an atmosphere, enough to overcome, without risk of dangerous consequences, the normal expiratory forces which tend to resist the inflation, there is observed a notable increase in the quantity of inspired air, *i. e.*, of the **vital capacity**; this results from the distention of the thorax and of the lungs. There is also an increase in **pulmonary ventilation** and in **gaseous interchange,** owing to the greater supply of oxygen and the stimulating effect of the heightened pressure on intrapulmonary diffusion. The act of **inspiration is facilitated,** as the inspiratory movement is assisted by the increased pressure. Expectoration is also rendered more easy, as the mucous secretions are thrust out by the forcible expiration that follows an abnormally deep inspiration. The thorax expands. The patients experience a sensation of fullness and weight; pallor and vertigo have occasionally been observed.

(B) **Expiration into Rarefied Air.**—A greater quantity of air is withdrawn from the lungs; the **lungs retract more** than under normal conditions, an observation that can readily be verified, since the circumference of the thorax diminishes and the diaphragm rises; **gaseous interchange** is stimulated within the lungs—in fact, a portion of the **residual air is aspirated**; in addition, the inspiration that follows an expiration into rarefied air is deeper than a normal inspiration or even than an inspiration in compressed air; **expiration is easier** and the work of the expiratory forces, the elasticity of the tissues, and the expiratory muscles, is diminished. There is a subjective sensation of constriction of the thorax, as if it were being forced in upon itself; and this sensation sometimes goes on to actual pain. After a certain

number of séances these effects become permanent. An **increase of the pulmonary capacity,** a **diminution of the volume of the lungs,** and an augmentation of the expiratory forces are sometimes observed.

(C) Expiration into Compressed Air.—Expiration being embarrassed, the normal **expiratory forces are stimulated** to greater exertion. The quantity of expired air diminishes and the pulmonary ventilation becomes less perfect.

(D) Inspiration of Rarefied Air.—The effect is inversely comparable with that obtained by expiration into compressed air: the quantity of inspired air is diminished, pulmonary ventilation suffers, and the **inspiratory muscles** are called into action more vigorously, so as to supply the lungs with a sufficient quantity of air.

Ducrocq attempted to verify the researches of Waldenburg by studying the effects on respiration and circulation produced by inspiration from condensed air with expiration into the same medium. Later experiments performed under similar conditions have confirmed his results. Ducrocq experimented exclusively on animals, and used a simple apparatus in which the condensed-air chamber could be instantaneously connected with the trachea (of the dog). The fluctuations in the blood-pressure were measured with Ludwig's manometer, and the respiratory variations with a pneumograph. In regard to the **effect on respiration,** Ducrocq's conclusions, in his own words, are as follow: Expiration is embarrassed. The pneumographic tracing is modified as a whole, so that the inspiratory curve is a vertical, straight line, while expiration is represented by an oblique broken line which is longer than under normal conditions. Expiration cannot be accomplished by the elasticity of the tissues alone, and the expiratory muscles are called into action. The first inspiration always exceeds in length the longest inspiration that the individual is capable of under normal circumstances, which explains why expiration cannot be effected by the forces that usually suffice in the normal state. If the pressure is sufficiently high to overcome the elasticity of the lungs, apnea results, persisting until the expiratory muscles begin to act; so soon as this takes place, regular respiration is re-established. The degree of pressure necessary to induce apnea depends on the age and strength of the animal.

Lebegott, a pupil of Lazarus, devoted his attention chiefly to the study of the **effects of expiration into rarefied air.** The most conspicuous effect is a **shortening** of expiration, which is proportionate to the degree of rarefaction. When expiration is abnormally prolonged, as in em-

physematous subjects, for example, the effect is even more striking. In the case of a patient who in standard air required seven seconds to complete the expiratory act, Lebegott found that expiration lasted only four seconds in air rarefied by about $\frac{1}{60}$ of an atmosphere.

Riegel and Franck, and Schreiber had already observed that the **effect on the blood-pressure** varies according as the observation is made at the beginning or at the end of a respiratory phase.

The following explanation of this phenomenon by Lebegott will help us to understand the variations of intrathoracic pressure that take place during an expiration into rarefied air. In the normal state intrathoracic pressure, which reaches its lowest point at the end of inspiration, rises steadily as expiration progresses; from being negative it rapidly becomes positive, and attains its maximum at the end of expiration. When the subject is made to breathe in rarefied air, communication is established between the pneumotherapeutic apparatus and an air-containing receptacle, the thorax, the pressure of which is not only higher than that of the pneumotherapeutic apparatus, but also tends constantly to increase. These communicating vessels, the apparatus and the thorax, are subject not only to an aspirating force, the rarefaction of the air in the apparatus, but also to the expiratory force of the thorax, which acts as a positive pressure—two forces which more or less completely neutralize one another during the entire act of expiration. Not until the end of expiration, when the expiratory forces of the thorax have normally come to the end of their efficiency, does the rarefying force of the apparatus enter into play. In other words, the chief advantage of Waldenburg's method, the supposed possibility of influencing respiration by accurate procedures, is absolutely illusory, unless it be admitted that the effect produced at the end of expiration represents the entire value of the method. If a water manometer which, owing to its wider oscillations, records the pressure variations much more accurately than the mercury manometer used by Waldenburg, is connected with the apparatus, it is observed that at the beginning of expiration into rarefied air there is an appreciable positive pressure, which is immediately followed by a diminution in pressure; in rare cases the latter remains constant during one or two seconds, or even undergoes some fluctuations during that time. This rarefaction corresponds to the ultimate negative pressure of the apparatus.

This ingenious explanation deserved to be cited verbatim. It does not conform altogether to the physical laws governing the transmission of pressure, but there can be no doubt that the observed facts exist.

There is a tendency toward pressure equilibrium so soon as communication is established between the apparatus and the thorax, but this equilibrium is constantly exposed to rupture by the intervention of the expiratory forces, especially the elasticity of the lungs; and it is only after the end of expiration that the manometer registers a permanent rarefaction.

In regard to **vital capacity,** Lebegott determined, under the most favorable conditions for observation, that vital capacity is not increased by expiration into rarefied air. Instead of studying the effect of a single expiration, Lebegott aimed to obtain as graphic a representation as possible of the effect of a long series of expirations into rarefied air. He concludes that the quantity of air expired into rarefied air, after a number of expirations succeeding each other without interruption, is considerably less than the quantity of air expired into atmospheric air.

Lang, another disciple of Lazarus, also studied the **effects of expiration into rarefied air** in normal and in emphysematous subjects. Although he used the old mask of Waldenburg, he took care to obviate the principal objections that are justly urged against observations made with this apparatus. Like Lebegott and others before him, Lang finds that expiration into rarefied air produces no increase in the vital capacity or in the total quantity of air expired. He admits that in emphysematous as well as in normal subjects a very small part of the residual air is withdrawn from the lungs; but this quantity is practically negligible, and is certainly far below that indicated by Waldenburg's figures. A much more unexpected result of Lang's investigations is that the degree of rarefaction is without influence on the quantity of air expired; the highest readings were obtained sometimes with a high and sometimes with a very low degree of rarefaction. In agreement with Lebegott, Lang found that the duration of the respiratory phase is inversely proportional to the degree of rarefaction.

Speck devoted years to the study of differential pressure apparatus and made every effort to achieve the most favorable conditions for experimentation, both as regards the apparatus and the subject of the experiment. A point that should be emphasized at the very beginning is the difficulty experienced by all persons, whether sick or well, in overcoming the embarrassment to the breathing that attends all respiratory experiments. The awkwardness exhibited by the subjects of experiments upon any question having to do with respiration is almost incredible, and it would seem that the mere thought of any embarrassment or limitation of the act of breathing suffices to provoke

acceleration of the respiratory movements, which at once become precipitate. Mere occlusion of the nostrils, if the subject has not been trained or warned beforehand, is enough to cause marked quickening of the respiration; and even when he has been duly warned the breathing retains the forced type. A full realization of this fact, which I have repeatedly had occasion to verify, is necessary to understand the many contradictions apparent in the results of the different investigators of this question. It demonstrates that the results depend largely on the individuality of the subjects experimented with—be they sick or well—and especially on their impressionability. This last factor is particularly important in sick persons. Another difficulty revealed by the work of Speck, Kempner, Lazarus, and many others who aimed at scientifically accurate results, is to find a mask that shall satisfy all reasonable demands. Waldenburg's mask was abandoned long ago because of its failure to satisfy the rigorous demands of experimentation; and every author has exercised his ingenuity in an attempt to devise a satisfactory modification. Unfortunately, every improvement is accompanied by an additional complication, and when impermeability has been achieved, the working of valves and stopcock is often sacrificed.

Speck studied the eight different combinations of differential pressure methods, four at least of which are of interest. These are: Inspiration of condensed air and expiration into rarefied air; inspiration of rarefied air and expiration into condensed air; inspiration of condensed air and expiration into condensed air; inspiration of rarefied air and expiration into rarefied air. The degree of compression or rarefaction was about $\frac{1}{88}$.

Inspiration of condensed air and **expiration into rarefied air** facilitate the respiration; it is natural to suppose, therefore, that the breathing becomes deeper, and that, conversely, **inspiration of rarefied air** and **expiration into condensed air** would cause a diminution of the respiratory interchanges. Speck, however, found that any combination of the eight that he studied always had the effect of increasing the ventilation of the lungs. This apparently paradoxical result becomes clear when we reflect that the act of breathing may be enhanced in two different ways: either by increasing the depth of the respiratory movements, or by increasing their frequency—the depth being the same. This is, in fact, what happens whenever respiration becomes embarrassed; that is to say, when the respiratory muscles are brought more forcibly into action, respiration becomes deeper. Whenever respiration becomes easier, the frequency of the respiratory movements increases.

These conclusions, which I accept in their entirety, cannot, however, be used as an argument for denying that pneumotherapeutic methods have any value; on the contrary, they will be utilized later to justify the therapeutic application of these methods. They appear to me to furnish a much better proof than do the assertions of Waldenburg that the employment of the so-called portable apparatus is justifiable; it is the *raison d'être* of their action in cases in which they are logically indicated.

General Conclusions

The facts in regard to the action of pneumotherapeutic methods determined up to the present time permit us to say that they render **respiration less difficult, less fatiguing** (inspiration of condensed air, expiration into rarefied air). Even in the normal subject an equivalent result cannot be obtained continuously by means of respiratory exercises, with the same degree of ease and for so long a period as with these apparatus; all the more, therefore, is it true in the case of the sick, for whom respiration is often a considerable labor attended with not a little fatigue—which we now have a means of lessening. The **quantity of air respired is increased,** no matter what combination is adopted, either because the inspiratory and expiratory forces are **stimulated to greater exertion** or because their action is rendered less difficult. A certain proportion of the **residual air is withdrawn** during expiration into rarefied air; and although this quantity is less than Waldenburg believed, it is nevertheless an appreciable quantity and materially assists in the ventilation of the lungs. Finally, the last and not the least interesting point is that expiration into rarefied air sensibly diminishes the **duration of a normal expiration,** and considerably shortens the expiration when prolonged by some pathologic process.

II. EFFECT ON THE CIRCULATORY APPARATUS

It is evident that the **heart and great vessels** contained in the thoracic cage must also be influenced by the pressure variations, but the results obtained by different authors in this respect present even wider variations than in the case of the respiration.

(A) Inspiration of Compressed Air.—Waldenburg asserts that the hyperdistention of the lungs tends to embarrass the intrapulmonary circulation. Systole becomes easier and the work of the heart is lightened; the pressure in the aorta rises; on the other hand, the flow of blood into the right auricle is hindered, as is shown by the turgescence of

the jugular veins. The quantity of blood in the aortic system increases, while that in the right heart diminishes. There is more blood in the systemic, and less in the pulmonary circulation, and this effect is more lasting than one would be inclined *à priori* to suppose. The general effect is the same as if a certain quantity of blood were withdrawn from the lesser circulation. The pulse is retarded, and its tension increased; the artery feels hard. The explanation of this retardation of the pulse is found chiefly in the diminished need of oxygen on the part of the economy, on account of the increase in the activity of nutritive interchanges.

In 1870 Gréhant reported to the Société de Biologie (Meetings of March 19th, June 18th, and June 28th) a series of experiments of his own which only partially confirm Waldenburg's researches, especially in regard to the compression of the pulmonary vessels and the diminution of the quantity of blood that flows through the lungs. These experiments were made on the curarized dog, on the normal dog, and on detached lungs. The pressure on the lungs arrests the circulation—blood-pressure becoming the same in the carotid artery and in the jugular vein. A pressure of 6 centimeters of mercury results in arrest of the heart after a few seconds.

In view of the discrepancy between the conclusions of Waldenburg and those of Gréhant, Ducrocq again took up the experimental study of the action of condensed air on the respiration and on the circulation.

Before giving the results obtained by this author, it may be well to recall in a few words the **physiologic effect of the respiration on the circulation.** Respiration reacts on circulation chiefly through the phenomenon of **aspiration,** which manifests itself in both phases of the respiratory act, but is much more marked during inspiration. There is a lowering of the intrathoracic pressure which makes itself felt on the heart and blood-vessels contained in the thorax. The flow of blood toward the thoracic veins and the right heart is facilitated, while its escape from the left heart and the arteries of the thorax is slightly impeded. The change in the intrathoracic pressure also affects the arteries, veins, and capillaries of the lungs, which, according to Donders, are subjected to a pressure lower than that of the atmosphere. To summarize the effects of respiration: it consists in an acceleration of the intrathoracic venous circulation which extends beyond the limits of the thorax, to the jugular veins in the neck and the inferior vena cava; a retardation of the lesser circulation and of the arterial circulation within the thorax. In addition, a deep inspiration, attended with forcible contraction of the diaphragm, is followed by an elevation of

the blood-pressure in all the vessels of the abdomen and in all those that leave it, as well as by an acceleration of the movement of the arterial blood toward the capillaries, and of the venous blood toward the thoracic cavity.

The **effects of respiration of condensed air on the circulation** are as follow: the circulation is retarded; there is a momentary increase of blood-pressure in the arteries, followed by a fall. The pressure rises in the veins, showing that there is some obstacle to the circulation between the arterial and the venous systems. In the left heart the same phenomena are observed as in the arteries; in the right heart the events are the same as in the veins; hence the impediment must be somewhere between the right and the left heart. The seat of the **obstruction** is in the **pulmonary vessels,** which are collapsed; and, if the pressure becomes sufficiently high, these vessels empty themselves suddenly into the pulmonary arteries and veins; nor does it require a very great pressure to bring about a momentary increase in the contents of these vessels. The flow of blood to the left heart is therefore momentarily increased to a considerable degree and the pressure rises; in addition, the lungs as they expand occupy the greatest possible amount of space in the chest, and accordingly compress all the other organs contained in it, so that the veins, the arteries, and the heart itself are subjected to greater pressure. As the volume of the vessels is diminished, the internal pressure, or tension, necessarily rises, provided there is no change in the contents. The left heart is unable to expel the usual quantity of blood during the first systolic contractions, since the blood strikes against a column of liquid which is under a greater pressure, and this again tends to raise the pressure in the left ventricle. So soon, however, as the peripheral arteries have sent a certain quantity of blood into the capillaries, and the heart has discharged its contents into the great vessels, the pressure within the heart falls, since the organ receives only a very small quantity of blood, or none at all, to replace the blood which it has expelled.

It follows that there is a **diminution of the flow of blood** into the **aortic system.** Contrary to Waldenburg's opinion, the increase in pressure in the aortic system is produced within a very short time—two or three systoles—at the very beginning of the experiment; and this initial rise is not due to the contraction of the heart; the explanation of the phenomenon that has just been given is the correct one. The action of the heart is not reinforced, since after a few systoles the left ventricle needs to make very little effort to expel the blood it contains. The **mean pressure in the thoracic arteries** falls during

inspiration and rises during expiration, just as under normal conditions. A similar phenomenon is often observed under normal conditions in the arteries situated below the diaphragm, according to the respiratory type of the animal experimented with. During respiration in condensed air the air enters the lungs without any effort on the part of the animal; the diaphragm is practically passive, most of the work being done by the respiratory muscles. The compression of the thoracic cavity is therefore even greater during expiration than during inspiration. The abdominal vessels are compressed to a greater degree, their caliber is diminished during expiration—another reason for the rise in pressure during that phase of the respiration. During all these variations, however, the pressure hardly ever attains the same point as under normal conditions. In the arteries situated below the diaphragm the rise in pressure, which is so marked in the arteries of the thorax at the beginning of compression, is therefore always inconsiderable. The **flow of venous blood into the ventricle,** on the other hand, is considerably increased; the greater the compression of the air, the more the pressure rises in the right ventricle and the greater the amplitude of the oscillations obtained with Ludwig's manometer—showing that the quantity of blood increases. The **rise of pressure in the veins** and in the right heart is sudden, and persists as long as the animal breathes condensed air; the elevation increases in direct proportion with the increase in pressure of the air respired. The variations in pressure that are observed under normal conditions with inspiration and expiration—increase of pressure during expiration, diminution of pressure during inspiration—are found also when compressed air is breathed, but the differences are less marked. The right heart strives to overcome the pressure in the pulmonary capillaries, but when this pressure attains a certain point it is unable to do so. The blood accumulates in the right heart and in the thoracic veins; the jugular veins become distended and turgescent.

The **velocity of the blood** in the arteries, measured with Oding's apparatus, is notably diminished. In the blood-vessels of all the various regions of the body a modification in the **amplitude** of the pressure-oscillations takes place. In the veins and in the right ventricle the amplitude of the oscillations increases as the pressure of the respired air rises; in the arteries and in the left heart the amplitude diminishes as the pressure of the air rises.

The **frequency** of the pulsations of the right ventricle and in the veins diminishes. The frequency of the pulsations in the arteries—the **pulse**—which diminishes slightly when the pressure first rises—

undergoes great augmentation if the pressure is not too great. When the pressure attains 3 or 4 centimeters in the case of young animals, or 5 centimeters in the case of full-grown animals, the pulsations of the left heart and of the arteries diminish in frequency and amplitude; and if the pressure is raised still more, the left ventricle and the arteries cease to beat.*

The work of Ducrocq, conducted with the greatest scientific rigor, therefore, appears to contradict Waldenburg's conclusions, and has been thus interpreted by all the authorities. For my part, I take a different view, and do not believe that the conclusions of Waldenburg should be rejected as a whole. Ducrocq's method consisted in connecting the animal's trachea with a reservoir containing condensed air, and making the animal inspire this air and expire into it for a considerable time. But this is not a perfect imitation of what happens when portable apparatus are used in which only the inspired air is condensed, while expiration is performed into normal or into rarefied air. If the inspirations are short, only the first phase of the circulatory phenomena observed by Ducrocq will be observed; the second, inverse phase, requires more prolonged inspirations for its production. Here we have **the explanation of the difference in the results** obtained by different investigators, according as they observed the beginning or the end of the inspiratory act. The events at the very **beginning of inspiration of condensed air,** during the first three or four systoles, may be described as follows: The pressure in the arteries is momentarily increased,† the pulmonary vessels collapse, so to speak, and the blood flows into the left ventricle in larger quantity; the pressure in both venous and arterial vessels within the thorax increases. The direct compression of all these vessels, provided the contents remain unaltered, results in an increase of the internal tension. The rise of pressure in the arterial

* Arrest of the heart is produced by a sudden increase of the pressure of the air in the lungs; it is not a mechanical effect, a simple arrest of the pulmonary circulation, as Gréhant supposes, but depends to some extent on nervous influences. Death does not always take place at the same pressure, but is more apt to occur when the increase of pressure is sudden. Nevertheless, the nervous influences are not central, since the result is the same after section of the pneumogastric nerves. Death may occur during the experiment, when it is due to asphyxia, the expiratory muscles being unable to renew the air in the lungs; or it may occur after the experiment, when it is also due to asphyxia, the inspiratory muscles being unable to resume their functions after the return to the normal state.

† v. Bosch, who is a competent authority on everything pertaining to the measurement of blood-pressure, also found that the arterial pressure was increased (plethysphygmograph of Mosso).

system is not due to the action of the heart—it is a purely mechanical phenomenon.

The flow of blood to the right ventricle increases rapidly from the beginning to the end of the inspiration. The velocity of the blood in the arteries is notably diminished. The amplitude of the oscillations of the blood-pressure increases in the veins and in the right heart, and diminishes in the arteries and in the left ventricle. The frequency of the pulsations diminishes in the veins and in the right ventricle, in the left ventricle, and in the arteries during the first three or four pulsations. If the inspiration is abnormally prolonged,—an ordinary inspiration lasts as long as four or five systoles,—the late, terminal or secondary action of inspiration of condensed air is observed.

Drosdorff and Botschetskaroff also regard the effects of inspiration of condensed air as purely mechanical in nature; when pure hydrogen is used instead of air, the same results are obtained. The same is true in regard to expiration into rarefied air. Section of the pneumogastric nerves does not affect the results of the experiments.

Sommerbrodt and Lenzmann, who also noted a lowering of the blood-pressure and an increase in the number of pulsations, attribute the phenomena altogether to **neuro-reflex influences.** The experiments of Ducrocq as well as those of Drósdorff and Botschetskaroff show the fallacy of the reasoning on which this opinion is based, and I must also take exception to it. Nevertheless the neuro-reflex phenomena are not altogether to be neglected in the interpretation of the effects of differential apparatus. The point will be reverted to again.

Riegel and Franck, in 1876, appear to have been the first after Ducrocq to study the question from the correct viewpoint and to recognize a **primary** and a **secondary** action. This distinction, which was demonstrated categorically in this very work of Ducrocq, seems not to have impressed that author, and it was only after the work of Riegel and Franck that it became an accepted datum. These authors studied the effects of inspiration of condensed air with the aid of a sphygmograph, and observed two distinct periods: an initial phase, and a terminal phase of opposite nature.

In disagreement with Waldenburg and with my own opinion, some authors disregard the primary period and regard only the secondary phase as the true expression of the action of condensed air, although the latter fails to appear if the precaution is taken **not to prolong the inspirations** too much; in most cases the first phase lasts about as long as a normal inspiration. It is the failure to appreciate this fact that complicates the interpretation of the many exact results arrived

at by investigators. Ducrocq himself, after accurately stating the facts observed, formally and sweepingly rejects the assertions of Waldenburg and takes account only of the secondary period. During the latter, the peripheral arteries having emptied themselves into the capillaries, and the left ventricle having discharged its contents into the arteries, the pressure in the left heart diminishes, since it receives only a minimal quantity of blood from the pulmonary veins; there is also a fall in the arteries and a rise in the right heart. The number of arterial pulsations (pulse) increases considerably unless the inspired air is under too high a pressure.

Such are the **conclusions** which in my opinion are deducible from the work of Ducrocq, published in 1878, and these conclusions I adopt after long and minute researches. Let it be recalled once more that Ducrocq himself arrived at an entirely different set of conclusions; which affords another proof that it is not always easy to interpret accurately the facts observed, especially in experimental work.

(**B**) **Expiration into Rarefied Air.**—According to Waldenburg, again, the effects of this procedure on the circulation are directly contrary to those attributed to the inspiration of condensed air. The quantity of blood in the lungs is increased; systole is embarrassed and the work of the heart is rendered more difficult; the pressure in the aorta diminishes; the flow of blood into the right auricle is facilitated. The quantity of blood in the aortic system diminishes and that in the pulmonary circulation is increased. The pulse becomes soft and compressible. The effect is the same as if a quantity of blood had been withdrawn from the greater circulation.

(**C**) **Expiration into Condensed Air.**—This procedure has been little studied and the studies have not been performed with great care. It is said to have the same effect as the inspiration of condensed air.

(**D**) **Inspiration of Rarefied Air.**—The effect is said to be analogous to that observed during expiration into rarefied air, but it is more marked. With a low degree of rarefaction the effect is the same as in expiration into greatly rarefied air, *i. e.*, to follow Waldenburg's comparison, the same effect as blood-letting. As regards expiration into rarefied air, which is generally used in combination with the inspiration of condensed air, Drosdorff and Botschetskaroff, Buntz and Lambert arrived at conclusions directly opposed to those of Walden-g. The latter's reply to their assertions has already been given. reasons previously cited to explain the results of these authors regard to condensed air appear to apply in this case also. This w is based on reasoning and clinical observation, and is, moreover,

supported by my own researches and by those of Schreiber, who, in 1878, observed a rise in the blood-pressure and an increase in the work performed by the heart; the pulse becomes soft and full. The same thing appears in Müller's experiment; but in the cardiographic and sphygmographic tracings obtained by Schreiber it is abundantly evident that there is a primary period during which a lowering of the blood-pressure takes place. When the negative pressure in the thorax has reduced the pressure in the veins of the neck and of the abdomen below that of the atmosphere, the walls of these vessels are compressed, the internal pressure or tension is increased and momentarily, at least, prevents the negative pressure from making itself felt in the remaining veins of the body, thus guarding against an excessive flow of blood toward the lungs (Zuntz). This difference between the condition of the walls and the internal pressure or tension was mentioned by Waldenburg. Zuntz, following the lead of Sommerbrodt, also mentions vascular innervation as a factor.

This exposition must suffice to show why, in regard to the effects on the circulation also, I find it impossible to accept the current view which denies that pneumotherapeutic methods have any physical effect whatever or any practical medicinal value.

III. EFFECT ON THE NUTRITION

Although in all his experiments, whatever the combination of differential methods employed, Speck observed an increase in the absorption of oxygen and in the elimination of carbon dioxid, he strenuously opposes the theory that this argues an increase of organic oxidation. As Lazarus says, Speck considers it very probable that the red blood-cells absorb a greater quantity of oxygen owing to the greater proportion of oxygen in the air that enters the lungs, and that the increase probably bears a direct relation to this greater proportion of oxygen or to the increase in the tension of the oxygen. On the other hand, he believes that his personal researches tend to show the fallacy of the conclusion that the increase in carbon dioxid exhaled with the condensed air points to increased absorption or more perfect utilization of oxygen. It is simply a more active elimination, not a more active production of carbon dioxid. At any rate, the increase in carbon dioxid elimination takes place indifferently whether condensed or rarefied air is inspired, or the individual merely engages in respiratory exercises in standard air. It is thus the result of an increase in the amplitude of the respirations both in inspiration and in expiration. Much might

be said about these figures as well as the interpretation proposed by Speck. I believe—and my researches on the respiratory coefficient and on the elimination of nitrogen by the kidneys amply justify the belief—that Speck goes too far when he attempts to show that the effects produced by the apparatus are solely osmotic phenomena. If a greater quantity of oxygen is supplied to the red cells, and they are at the same time enabled to eliminate carbon dioxid more actively, are they not thus better able to perform their functions as agents of the general respiration, and as directors of the nutrition of cells in the entire organism?

Geigel and Mayer observed an increase in the quantity of urine in healthy subjects after the inspiration of condensed air; this diuretic action of the procedure is also observed in persons suffering from heart disease (Rosenstein); and Kelemen observed it in patients with pleural effusion. In addition to these facts, the mechanism of which is readily understood by a consideration of the action of pneumotherapeutic methods on the respiratory and circulatory apparatus, an improvement in the appetite and in the general condition has also been determined.

IV. NEURO-REFLEX PHENOMENA

It has been established that most of the phenomena observed in patients submitted to the various pneumotherapeutic procedures are explainable on mechanical grounds. But a very different theory is defended by a number of authors—among them Sommerbrodt. In this view, the primary effect of the inspiration of condensed air is an increase of intrabronchial pressure, similar to the effect produced by speaking, crying, singing, running, swimming, and other active exercises. This increase of pressure produces certain **reflex** effects: a diminution in the tone of the vasomotor fibers and a relaxation of the walls of the blood-vessels, resulting in acceleration of the contractions of the heart and a diminution of the intracardiac pressure. This desirable effect on the circulation explains the influence on metabolism, diuresis and the like. Sommerbrodt's theory is open to many criticisms from the physiologic standpoint, and is absolutely contradicted by the experimental researches detailed above. It has, nevertheless, been accorded a place in this discussion because the nervous system, in truth, is not without an actual and important influence in the sum total of the effects of the differential methods. There is no need to revert to the claims of the opponents of pneumotherapy, that the effect of the apparatus is purely psychic and represents a true suggestion. Whoever

has used these apparatus must admit that their employment is followed by a distinct improvement of the respiratory movements. As Speck justly observes, it is impossible to obtain by means of respiratory gymnastics, even when used repeatedly, the same effects as with apparatus for inspiration of condensed air and expiration into rarefied air. This fact alone, which should suffice to establish their claim as a therapeutic method, applies not only to the normal individual; the effects are even more marked in those who suffer from chronic embarrassment of the respiration and have to make an actual effort each time they draw a breath (emphysema). But is the effect altogether a mechanical one? There are certain observations that suggest some influence on the part of the nervous system. Physiologists, as Horing and Brener, have shown that mere distention of the lungs enhances the effects of inspiration, while, on the other hand, retraction of the lungs increases the effects of expiration. These factors, therefore, add to the result.

General View of Differential Pneumotherapy

We may here insert for comparison, and as a means of focusing the practical results of our discussion, the **conclusions formulated by the editor** of this series and published as the result of his studies a few years ago. In most respects they are virtually identical with my own. My therapeutic recommendations will be reserved for detailed statement in the section immediately following.

The physical effects of respiratory differentiation must be considered with reference, first, to **respiration;** second, to **circulation.** Motion of air and of blood takes place from the point of high pressure toward the point of low pressure. **Increased pressure** upon the pulmonary surface, therefore, favors the entrance of air into the chest and the expansion of the lungs, and opposes the exit of air from the chest and the contraction of the lungs; thus it **facilitates inspiration** and **impedes expiration.** It tends to drive the blood out of the heart, out of the thorax, and toward the periphery. **Decreased pressure** upon the pulmonary surface **facilitates expiration** and **impedes inspiration.** It tends to drive the blood from the periphery toward the thorax and into the right heart. Modification of these tendencies results from **neural** and especially **vasomotor** reaction.

Inspiration of Condensed Air with Expiration into the Atmosphere

Technic.—The excess pressure employed varies from $\frac{1}{80}$ to $\frac{1}{80}$ of an

atmosphere (+ 9.5 to + 25 mm. Hg). From 10 to 150 respirations may be made continuously, and the process repeated after a rest of from five to fifteen minutes. The patient, if able, should stand, with head erect and shoulders thrown well back. (See Fig. 36.) If necessary, the physician or an attendant should aid **inspiration** by pressing the shoulders backward, or assist **expiration** by compressing the chest. When it is desired to **localize** or locally increase the effect, the indifferent or healthy portion of the chest may be strapped, or its motion diminished by manual or mechanical pressure or by a suitable pad and brace (see page 277).

Respiration.—The muscular effort of inspiration is diminished and the alveoli are dilated to a greater extent than would be possible from unaided voluntary effort. There is increase in the quantity and in the penetrating power of the inspired air, therefore reopening of air-cells, disused from weakness or occluded by swelling of the bronchi, by pathologic secretion, and the like. There is augmentation of the volume, and of the weight relatively to volume, of oxygen brought to and absorbed by the blood, a much greater area of blood-surface being reached. The subsequent expiration is sometimes slightly retarded, though theoretically it should be easier in all cases. It is deeper than usual, the quantity of air expelled, and thus of carbon dioxid eliminated, being increased. Tidal and complemental air being thus augmented, reserve air diminished, the first two quantities and a portion of the third quantity become added to form what is now virtually an **increased volume of tidal air,** reaching 200 cubic inches or more. Diminished frequency of respiration, increased expansion, ventilation, and gaseous exchange are therefore the immediate effects; **increased vital capacity** the ultimate and permanent result. In some cases the increase of chest measure is remarkable. It is not due to a pathologic emphysema, as expiration can be performed perfectly.

Circulation.—During inspiration there is an augmented centrifugal tendency of the blood-current. The ventricular systole is increased in force. Both arterial and pulmonic circulation are at first quickened, bringing more blood, therefore more corpuscles, more hemoglobin, in proportion to area, in contact with the increased quantity of inspired oxygen. The systemic vessels are filled, causing a rise of arterial blood-pressure. The pulse becomes at first more frequent, but afterward slower, full, and hard. The blood circulates more actively throughout the body, penetrating more readily into capillaries and lymph-spaces, and being richer not only in oxygen but also in nutritive materials; for pressure upon the diaphragm transmitted to the abdominal viscera stimulates absorption of chyle, while heightened pressure and augmented quantity

of blood in the viscera tend to stimulate functional activity. The waste products of metabolism are more thoroughly removed. Thus, increased oxidation and tissue change heighten appetite and improve nutrition; the enlarged alimentation is utilized; there is better combustion and elimination.

The effect upon pathologic conditions is due partly to the general effect upon respiration, circulation, and nutrition, partly to reflex or reactionary nervous and vasomotor influence, and partly to local mechanical pressure. When pulmonary hyperemia exists, it is relieved. The absorption of inflammatory products is hastened. The general tone of the bronchial mucous membrane and the pulmonary tissue is heightened. Cough and expectoration are at first increased from dislodgment of accumulated materials, afterward diminished from relief to irritation and diminution of pathologic secretions. Increased ingestion and assimilation repair pathologic waste, and the increase in weight sometimes exceeds the previous record in good health. Toxic metabolins, whether autogenetic or heterogenetic, are destroyed and removed; useful metabolins are again formed. Thus fever is diminished, sleep is promoted, night-sweating is often arrested, and hemoptysis is sometimes checked.

Indications.—Inspiration of condensed air is chiefly employed in cases of **deficient expansion, deficient ventilation, deficient oxidation,** and **impaired circulation,** as in anemia, lithemia, pulmonary tuberculosis, chronic bronchitis and bronchorrhea, chronic pneumonia, chronic pleurisy (with effusion or adhesions), bronchial asthma, arterial hypotension, and, with caution, in certain cases of dilatation of the heart. In many of these conditions its efficacy may be increased by combining with it **expiration into rarefied air.** (See page 255.)

Expiration into Condensed Air following Inspiration of Normal Air

This procedure **impedes the act** of expiration and necessitates greater muscular exertion. If this be sufficient to overcome the obstruction, the amount of air expelled is increased. Otherwise it becomes gradually diminished, and the subsequent inspirations are therefore rendered shallower. In other words, tidal air is at first increased, but soon diminished; residual air gradually encroaches upon reserve air, upon tidal air, and finally upon complemental air, the entire volume becoming practically stationary or residual. The excursions of the diaphragm and thoracic walls become less and less, but at the expense of the contraction, fixed expansion being finally maintained, and if the procedure be pushed to excess with too high a pressure, apnea may result. Pulmonary ventilation is diminished and gaseous exchange is retarded,

the absorption of oxygen by the hemoglobin being, however, facilitated, although the excretion of carbon dioxid is diminished. The effect upon the **circulation** produced during expiration is in much less degree relieved by subsequent inspiration than in the converse case, and is thus an exaggeration of that caused by inspiration of condensed air; being practically the same as in Valsalva's experiment—depletion of the lungs and heart, and overdistention of the systemic vessels, especially the veins. The pulse may disappear from compression of the subclavian artery. Upon pathologic conditions the pressure effects are similar to those already detailed. The expedient is chiefly **useful** for pulmonary exercise.

Continuous respiration of condensed air greatly augments the distention of the thorax and of the lungs, maintaining the patency of the alveoli; and while it diminishes during treatment the volume of air exhaled, the ultimate result is a great increase in vital capacity. The ventilation of the lungs is but temporarily diminished, and, on the whole, gaseous exchange appears to be slightly increased. There is constantly increasing interference with the dilatation of the heart, and an outward pressure replaces the normal thoracic aspiration of the blood, thus blocking the systemic veins, while at the same time the arteries are distended. Arterial tension, increased at first, soon falls, and the pulse becomes small, slow, and feeble. The method is **indicated** chiefly to relieve **congestion,** stimulate **absorption,** or increase **vital capacity;** thus in dilatation of the heart, mitral insufficiency, persistent pneumonic consolidation, pleural effusion, or after thoracocentesis. It is practised in the Williams cabinet with good results in pulmonary tuberculosis.

Inspiration of Rarefied Air with Expiration into the Atmosphere

This should be conducted against a very feeble negative pressure, rarely exceeding $\frac{1}{60}$ of an atmosphere. It **increases the muscular effort** necessary to produce expansion of the chest, and the volume of air needed to supply the requisite weight of oxygen for the demands of the organism. If the effort can duly be made, there is increase in the elastic tension of the lungs and in the volume of tidal air. If it cannot be made, there is decrease in both these factors. The subsequent contraction of the chest is at first passively facilitated, afterward impeded, from the resistance of the denser outer air. The muscular effort of this phase is thus also increased, and the frequency of **respiration,** at first heightened by the excitement of impediment, is finally diminished. Ventilation and gaseous exchange are, on the whole, increased, vital capacity is augmented, and the muscles of inspiration are strengthened. The **blood** tends at first to leave the periphery

and accumulate within the thorax; but as there is more blood delivered to the left ventricle, and this can contract with sufficient force to overcome the higher peripheral pressure, the final result is a quickening of the circulation with heightening of the blood-pressure.

Inspiration of rarefied air, with expiration into condensed air, increases the muscular effort necessary to complete each act, prolongs the respiration, and retards expiration particularly. The alternation of centripetal and centrifugal impetus increases the activity of circulation. The method is used for **pulmonary development.**

Expiration into Rarefied Air, following Inspiration of Normal Air

This procedure, conducted with a negative pressure of from $\frac{1}{60}$ to $\frac{1}{30}$ of an atmosphere, favors the contraction of the thorax in respiration, and greatly increases the amount of air expelled from the lungs, thus facilitating the collapse of distended air-vesicles. Subsequent inspirations are rendered easier and deeper, more oxygen-bearing air enters the vesicles, ventilation and gaseous exchange are enormously increased, and the gain in vital capacity is very great. The **circulatory effects** are similar to those produced by inspiration of rarefied air, but more marked. They vary in different individuals, are evidently different in man and animals, and can be influenced by the manner of subsequent inspiration. Observations as to systemic blood-pressure conflict, but there is agreement as to the tendency to pulmonary congestion and the facilitation of cardiac diastole. The method is **employed** chiefly in cases of asthma and of vesicular emphysema, with due caution when there is much dilatation of the heart.

Inspiration of rarefied air, with expiration into the same medium (continuous respiration of rarefied air), increases the muscular effort of inspiration, but hastens and facilitates expiration. The centripetal tendency of the blood is maintained during the entire act, and the heart's action is greatly diminished in force and increased in frequency, the general arterial tension being much lowered. The method is rarely used.

Inspiration of condensed air, with expiration into rarefied air, markedly increases the efficiency of both procedures. The alternate expansion and contraction of the lung tissue stimulates its elasticity. Pulmonary ventilation, both as to interchange of gases and expulsion of effete materials, is vastly augmented. The alternations of opposing circulatory effects relieve hyperemia, increase the activity and penetrating power of the blood-current, and stimulate tissue change and nutrition. The combination is therefore especially **useful** in pulmonary tuberculosis, in bronchorrhea, and in all forms of asthma.

THERAPEUTIC APPLICATION OF DIFFERENTIAL PRESSURE METHODS

I. DISEASES OF THE RESPIRATORY APPARATUS

It was natural to seek the first application of differential pneumotherapy in diseases of the chest; and the observations of Waldenburg were followed by the publication of numerous monographs, most of which confirm his conclusions. The most uncompromising opponents of the method admit that in certain cases of **chronic bronchitis** results can be obtained that no other therapeutic means would yield; but their conclusion, as will appear, is rather severe as to the principle of the method.

General Indications

Inspiration of condensed air is indicated (1) when the **breathing is feeble** and liable to disturbance by the slightest effort, as in certain forms of **bronchitis** and in **stenosis** of the upper air-passages; (2) when **pulmonary expansion is insufficient** either on account of incomplete unfolding of the organ from disease, as in **convalescence from pneumonia,** in **atelectatic** conditions, and the like; or on account of congenital or acquired **limitation of the respiratory area;** (3) to bring about the **expulsion of morbid products** in the bronchi or vesicles, or the **absorption of pleural exudates;** (4) in the presence of pathologic modifications of the respiratory interchanges, chiefly those resulting from **hyperemia;** and (5) as a **prophylactic régime** for subjects presenting the so-called **phthisical habit,** or what is known as a **paralytic thorax.**

Expiration into rarefied air, on the other hand, is indicated (1) when the lungs are **abnormally distended** and the **expiratory forces too feeble** or altogether deficient, and the gaseous interchanges are thus diminished on account of insufficient retraction of the lungs; (2) when the **pulmonary circulation is insufficient.** In general, therefore, it is to be employed in certain forms of **chronic bronchitis,** in **emphysema,** and in **diseases of tuberculous origin.**

Some of those who have made a close study of pneumotherapeutic procedures have reached conclusions that I cannot accept, but which, in fairness, I must state. Lazarus, at the Congress of Internal Medicine at Berlin (1882 and 1883), was the first to cast a doubt on the action and the utility of pneumotherapeutic apparatus. In the course of the discussion, attention was called, among other things, to the possible danger attending a sudden change of pressure affecting not only the bronchi but also the large blood-vessels in the thorax. Since then

the same authority, in his treatise on pneumotherapy, teaches that the good effect of the apparatus is confined to a small number of cases of chronic disease of the respiratory apparatus, in which they act by inducing and facilitating respiratory gymnastics. He lays great stress on the difficulty of maintaining a **constant pressure** in the apparatus after communication with the respiratory passages has been established. Even with the apparatus of Geigel and Mayer, which Lazarus regards as the best in this respect, the pressure is not quite constant. At the very beginning of expiration into rarefied air the manometer frequently indicates a positive pressure; and the pressure in the apparatus does not become negative until the expiratory act has ceased; at most, he argues, the desired result is fully obtained only at the end of expiration, when part of the residual air has been withdrawn. This objection has already been answered from the physiologic standpoint: the object is not to suppress the action of the normal expiratory forces, which tend to increase the pressure, but to reduce the opposition to that action. The difficulty might be gotten rid of by employing an apparatus with a larger receptacle for rarefied air, and is indeed obviated in S. Solis Cohen's apparatus by the constant withdrawal of air from the expiration cylinder by means of the bellows. It seems illogical, however, to demand in every case a constant negative pressure in the apparatus from the very beginning of expiration; all that is necessary, is to know whether or not expiration is rendered easier by the fact that the air escaping from the lungs has to overcome a resistance less than that of the atmosphere. That this must be so is *à priori* evident, and Lazarus admits it by implication. His disciple Lebegott has proved that under these conditions expiration is much shorter, and Lazarus indeed uses as an argument against the employment of rarefied air that the greater velocity of the expiratory air-current acts as a mechanical irritant capable of provoking defensive reflexes analogous to those induced by direct insufflation of air into the larynx. This irritation is evidently not without some importance, and its occurrence helps to explain the observation of Lebegott, that the degree of rarefaction has no influence on the quantity of air expired, which is even diminished when the rarefaction is too great.

Lazarus also argues that the increased velocity of the expiration is of no advantage, the quantity of expired air remaining the same. Without discussing the latter point, it may be said that it is well known that a small quantity of residual air is constantly withdrawn from the lungs, especially in persons suffering from disease. But the increased velocity of expiration is in itself a considerable advantage

as regards the breathing; the expiratory forces are economized, since their action is assisted during the entire period of expiration, and they are therefore called into effort for a shorter time. The effect is, in short, that the demand on the expiratory forces is less and their action abridged. In addition, the shortening of the expiration has a beneficial effect on the pulmonary, and on the general circulation.

Lazarus further contends that the favorable results said to have been obtained in disease cannot be explained by the conclusions drawn from researches on healthy individuals; it is only in a small number of chronic diseases of the respiratory system that such effects have been positively determined, and the results must be attributed solely to the **respiratory gymnastics** provoked and assisted by the apparatus. That the apparatus merely represent a means of respiratory gymnastics may be conceded; it is evident, however, that this form of respiratory gymnastics is possible only with their aid. In other words, they afford a special kind of respiratory exercises which, without being absolutely specific, must nevertheless be clearly distinguished from the exercises attainable by purely muscular methods.

The conclusions of Lazarus are substantially as follow: It is a matter of indifference which one of the instruments proposed is employed; the essential thing to be remembered is that the want of energy on the part of patients is effectually corrected by the **suggestive** influence of the apparatus itself, so that the patients give themselves up to the respiratory gymnastics with more enthusiasm and more success than they would without the aid of the machines; and this is their sole merit. Knauthe and Hoffmann adopt the same view as Lazarus. Even if every other merit be denied, however, the use of apparatus as a method of invoking the action of psychic suggestion is not to be despised. The physician is at least assured that the respiratory exercises he prescribes will be carried out correctly and systematically.

Diseases of the Upper Air-passages

In the **acute forms,** the use of differential pressure has been abandoned; but if the air of the apparatus be saturated with **medicinal vapors**—as menthol in particular—good results may be obtained in cases of **acute laryngitis,** and especially in cases of **tracheitis,** which are so rebellious to every other kind of treatment. In **chronic affections** of the upper air-passages accompanied by stenosis, the action of the apparatus is of little value and is to be regarded merely as a palliative.

Bronchial Affections

Practically all forms of bronchial disease have been treated by the differential method with very variable results. Cross reports recovery from the most intense **acute catarrh,** following **inspiration of condensed air** charged with aqueous vapor or with the vapor of **ammonium chlorid,** the patient taking 20 to 30 inspirations at each séance, and repeating the process two or three times a day.

Chronic bronchitis varies so much in both the character and the seat of the lesions that it is impossible to group the various forms under a single nosologic head for the purpose of determining the effect of pneumotherapy. Kelemen's plan is to begin by studying the type of the respiration with the pneumatometer; if inspiration is found to be deficient, he advises **inspiration of condensed air;** if, on the contrary, expiration appears to be too feeble, **expiration into rarefied air** is the better method. Bronchitis may be limited to the large bronchi or it may be localized chiefly in the smaller tubes; in the latter case it produces a constant, habitual dyspnea on account of the swelling of the mucous membrane and the narrowing of the lumen of the bronchi, and sometimes more or less violent paroxysms of dyspnea whenever the secretions accumulate on the surface of the mucosa. In these cases, which are always complicated by some degree of **emphysema,** and in which one or two lobules are usually atelectatic, the inspiration of condensed air is useful in overcoming the obstacles; besides, each inspiration is followed by a vigorous expiration, which often succeeds in dislodging the masses of mucus. When emphysema is marked, expiration into rarefied air may be advised at the same time.

Certain **varieties of chronic bronchitis** should be mentioned especially. In **fetid or putrid bronchitis** the **inhalation of condensed air** charged with **medicinal vapors** such as benzoin, carbolic acid, creosote, myrtol, terebene, eucalyptus, formaldehyde, is of decided value, as it facilitates expectoration and is the simplest, most practical, and at the same time the most efficient means of carrying the volatile medicament to the seat of the disease. It is only necessary to compare the results of this procedure with those obtained by simple inhalation, to be convinced of its great usefulness.

The old division of bronchial catarrh into dry and moist is as justifiable in a therapeutic sense as it is clinically. In **moist catarrh** with frequent cough, dyspnea, and abundant expectoration, Knauthe obtained the best results with **expiration into rarefied air,** which he sometimes combines with **inspiration of condensed air.** Biedert

believes that these methods have an absolutely specific action in such cases. The cough becomes easier, expectoration diminishes and soon disappears, dyspnea gradually lessens and ultimately subsides altogether. Permanent cure is not often possible; but the improvement is marked and lasts for some time, so that the patients are always willing to undergo another course of treatment when it becomes necessary. As is true, however, of all therapeutic expedients, of whatever description, absolute failure is sometimes encountered in cases in which the indication has seemed to be quite clear.

In **dry catarrh,** either **expiration into condensed air** or **continuous respiration of condensed air** is usually the best procedure.

Diseases of the Lungs

Emphysema.—It is in emphysema that the apparatus have been chiefly used, and especially in emphysema complicating **chronic bronchitis.** This disease will therefore be discussed first in speaking of the application of the apparatus in diseases of the lungs.* Let it be understood at once that most of the observations reported of **asthma** treated with pneumotherapeutic apparatus refer to cases of **secondary asthma,** or of **emphysema with asthmatic attacks.** The essential nature of emphysema is even at the present time shrouded in obscurity, although the pathologic lesions as well as the clinical symptoms are quite well known. Emphasis should be placed on the fact that the **secondary emphysema** observed with certain pulmonary lesions characterized by sclerotic changes, such as fibroid phthisis, for example, responds only by a temporary improvement to the use of the apparatus. It is not the nature of the initial disease that is responsible for this want of success; for I believe that even the most typical emphysema will be found, on careful examination, to rest on a tuberculous base; in fact, I consider emphysema as an attenuated, benign form of pulmonary tuberculosis, fibrous in its development from the beginning. But in the cases now under discussion the lesions are coarse and quite easily recognized, and it is indeed their extent that explains the want of success of the method in a disease in which emphysema is, so to speak, a mechanical result—an *emphysema necessitatis.* At the beginning, when the emphysema is slight and is unnoticed even by

* The employment of inspiration of condensed air in **pneumonia** (Waldenburg) which is said to be followed by prompt diminution of the dyspnea (Amiati) may be dismissed at once, as it is a procedure too dangerous to be recommended. It is true that the blood is expelled from the capillaries, but only for a very short space of time, and it returns in even greater abundance than before; while infection may be diffused to a greater extent.

the patient himself, betraying itself only by slight dyspnea on exertion and a faint change in the respiratory murmur—although even at this time a positive diagnosis is possible with the pneumatometer—expiration into rarefied air gives marvelous results and, according to Kelemen, may even effect a cure. Kelemen, indeed, goes even further, and believes that emphysema and the accompanying bronchitis can be cured whenever the expiratory force (as measured with the pneumatometer) and the vital capacity are not diminished by more than one-half. It is in the emphysema of **bronchial catarrh,** which this author regards as a special disease,* that the effect is most rapid. When, however, the expiratory forces, especially the pulmonary elasticity, have become permanently enfeebled, and when cardiac troubles supervene and bring on passive hyperemia of the lungs, all that can be hoped for is a very transitory improvement.

Expiration into rarefied air diminishes the abnormal length of the expiratory act and renders it less labored, assists the retraction of the lungs, promotes expectoration, withdraws a certain quantity of residual air, and increases the pulmonary capacity. The cases in which I have obtained good results are so numerous that I cannot for a moment admit that they were due to suggestion, even in the sense proposed by Lazarus and Hoffmann. Following the example of the majority, I have employed only the method referred to; it should be remembered, however, that Waldenburg, whenever he found that the inspiration was deficient—and that is not a rare occurrence—would begin the séance by having the patient inspire for ten to fifteen minutes air compressed from $\frac{1}{100}$ to $\frac{1}{60}$ of an atmosphere; and in America, DaCosta and S. Solis Cohen have likewise reported good results from this combination of expedients.

Asthma.—True asthma has also been studied in relation to the therapeutic value of the apparatus. **Inspiration of condensed air,** and **inspiration of condensed and rarefied air combined,** have been employed; in the latter case the treatment is begun with condensed air, the change to rarefied air being made toward the conclusion of the séance. During the **intervals** between attacks Cross advises that inspirations of condensed air be continued perseveringly, and when an attack occurs, that the compression be increased as high as $\frac{1}{30}$ or even $\frac{1}{20}$ of an atmosphere. In this manner he says the attack is relieved and its duration abridged. J. Solis-Cohen also advocates high degrees of pressure.

* This form of bronchitis, according to Kelemen, has its origin in a disturbance of the nutrition secondary to a modification of the intrapulmonary gaseous interchanges.

Ducrocq, on the other hand, advises that only a low degree of compression be used—4 centimeters of mercury for an adult and 2 for a child. This pressure, he says, is enough to overcome the spasm of the small bronchioles and thus to insure renewal of the air inclosed in the alveoli. It is also important that the time during which the lungs are in contact with the condensed air should not exceed the average duration of a normal inspiration.

Reserving for a special paragraph the employment of the apparatus in **tuberculosis,** we now come to their use in pleural affections.

Diseases of the Pleura

Pleuritis.—In **serofibrinous pleurisies** recourse may be had to pneumotherapy after the fever has subsided, should reexpansion be delayed. **Inspiration of condensed air** is ordinarily used, one or two séances a day being prescribed. Waldenburg is the only one who sometimes in the case of youthful patients uses, along with condensed air, inspirations of feebly rarefied air ($-\frac{1}{400}$ to $-\frac{1}{200}$ of an atmosphere). He does not recommend this practice, however, so long as dyspnea and pain in the chest persist, or in feeble subjects. Kelemen explains the good results obtained by this method of treatment, partly by its mechanical effect and partly by the diuretic action, which has been mentioned in another place. Inspirations of condensed air have also been advised **after thoracocentesis** (Burresi, Solis-Cohen), to promote the unfolding of the lung. All the authorities—Waldenburg, Lazarus, Solis-Cohen and others—agree on the great value of the apparatus to overcome **pleural adhesions** in their early stages. Either the inspiration of condensed air alone is employed; or the treatment is begun with a certain number of séances of **expiration into rarefied air** in the hope of breaking up the pleural adhesions (Kelemen). After this has been accomplished, condensed air only is employed. Kelemen declares that the mobilization of the affected areas can be ascertained by means of auscultation, which reveals a reappearance of pleural friction sounds. In this way he was able to remove pleuropericardial adhesions in two cases in which the result was later demonstrated by an autopsy. In these cases he utilized a high degree of rarefaction.

Empyema.—Quite recently I have had occasion to observe truly marvelous results from pneumotherapy in a case of monomicrobial purulent pleurisy due to an extremely virulent form of streptococcus. Operative interference had been followed by only temporary subsidence of the symptoms, the purulent effusion was very abundant, and the phenomena of general infection were becoming alarming, when I advised

that the patient be given two séances a day of 20 to 30 **inspirations of feebly rarefied air,** at the time of the dressing of the wound. The effect was not slow to declare itself; the drainage of the pleural sac became much more perfect, the cautious expansion of the lung having a much better effect than irrigations, which, as is well known, are not always free from grave objections.

Another effect of the treatment is to bring about a desirable change in the condition of the lung by acting on the circulation and on the adhesions which tend to fix the organ firmly in a short time.

Pulmonary Tuberculosis

The question of the value of pneumotherapeutic apparatus in this important disease has been the subject of animated discussion. Although recommended by Waldenburg and Fenoglio, pneumotherapy with the aid of differential apparatus signally failed in the hands of Knauthe, and is now considered dangerous by many authors. Ducrocq asserts that it exposes the walls of the smaller bronchi and of the alveoli to the danger of laceration; and the method has also been accused of causing **hemoptysis.** The latter appears to be the pivotal point of the dispute. There can be no doubt that the apparatus are capable of rendering great service in a disease which, in its local lesions as well as in its reaction on the general condition of the body, presents the very conditions that are known to be influenced by active pneumotherapeutic methods. The question to be answered, therefore, is not whether the apparatus are useful; but whether there is reason to fear that their employment will lead to the occurrence of grave accidents. The question is not an idle one; for, were it not for this fear, the method would find its most frequent and most successful application in pulmonary tuberculosis. It will be generally conceded that all cases of **febrile** tuberculosis, of phthisis with attacks of **congestive** phenomena, of **hemorrhagic** phthisis, of **rapidly progressing** phthisis, and of advanced phthisis with **cavity-formation,** must be excluded as **unsuitable** for this method of treatment. But in ordinary cases of **torpid tuberculosis** in which the lesions are localized at the apices, in which there is no softening or at least only a limited degree of softening, and the progress is slow, the use of pneumotherapeutic methods is at least worthy of consideration. Jaccoud and S. Solis Cohen go further, and say that in such cases the physician who neglects to employ them fails to perform his whole duty. During the initial stage when, except for a slight general impairment of strength, the patients present only a little dry cough and faint modifications of the

physical signs at the apex, exaggeration of the vocal resonance, roughened breathing, prolonged expiration or even less, should the fear of possible accidents cause us to withhold the best remedy in our possession for influencing both the ventilation and the circulation of the lungs? This is not my opinion; and experience teaches that, although the value of the apparatus may have been exaggerated, and they may not in themselves suffice to bring about a cure in the majority of cases, they constitute, nevertheless, one of the most efficient means of combating the threatening infection of the lungs.

I employ only the **inspiration of feebly condensed air,** either pure or saturated with **medicinal vapors,** and have never had any accident that could be attributed directly to the method. This is the practice that is recommended by Fenoglio, who begins with low pressures of $+\frac{1}{150}$ of an atmosphere and gradually attains a pressure of $+\frac{1}{50}$. It is also Kelemen's practice in cases of **apical catarrh,** which, he declares, he generally succeeds in causing to disappear; at the beginning of the treatment he adds **expiration into rarefied air.** I have never employed the method of Waldenburg, who in cases entirely free from any tendency to hemoptysis administers a few **inspirations of rarefied air** after the inspiration. Solis-Cohen employs **inspiration of condensed air** with **expiration into rarefied air;** gradually increasing the positive and negative pressures to a limit of $+\frac{1}{30}$ and $-\frac{1}{50}$ atmosphere, respectively.

In giving inspirations of condensed air it is important to use a low pressure, and to see to it that the inspirations do not last more than three or four seconds at most. S. Solis Cohen, however, advocates in certain cases the gradual and cautious prolongation of the period of inspiration and maintained expansion (holding the breath) at successive séances until it reaches five or six seconds. I have not practised this method. The statement may again be made that the time, duration, frequency, and force of the procedures adopted must be adjusted to the needs of the individual patient; thus the physician must, in large measure, be guided by the results in the particular instance.

The **effect of the procedure** when thus carried out in special cases is to bring into action, one after another, those portions of the lungs which, on account of the pathologic conditions present, are in danger of forfeiting their physiologic function. In addition, it induces the kind of respiratory gymnastics previously referred to, and which is especially indicated in such cases; promotes the gaseous interchanges and restores the appetite in patients who habitually have little desire for food. As the editor of this system justly remarks, the systematic use of the

apparatus brings about an improvement of metabolism, reflected in the increased appetite, which enables the physician to resort to superalimentation even in cases in which all digestive remedies have failed. Finally, one of the principal advantages of inspirations of condensed air is that they afford a means of successfully combating the **arterial relaxation** (**hypotension**) that is constantly present in hypotrophic subjects, even in the early stages, before the appearance of any physical signs. It is well known that the arterial tension in tuberculous patients, as measured with Potain's sphygmomanometer, falls as low as 10 or 12 centimeters of mercury—normal pressure being from 15 to 17 centimeters. This condition, which is important enough to merit further and full discussion, will be referred to again.

II. DISEASES OF THE CIRCULATORY APPARATUS

Waldenburg is warm in his praises of the differential method of pneumotherapy for the relief of diseases of the circulatory system. He recommends the **inspiration of condensed** air whenever it is desirable to reinforce the action of the heart-muscle or to increase the blood-pressure in the aortic system. In this way, he asserts, the blood in the chambers of the heart is more perfectly evacuated; the flow of venous blood from the greater circulation is momentarily diminished; the quantity of blood in the lungs is lessened, while the greater circulation is overloaded. Inspiration of condensed air is therefore indicated, according to Waldenburg, in **mitral insufficiency** and **mitral stenosis,** and in **aortic insufficiency. Expiration into rarefied** air is indicated when it is desired to lower the pressure in the aortic system, to facilitate the flow of venous blood toward the heart and into the pulmonary vessels, and at the same time to reduce the quantity of blood in the general circulation. Rarefied air is therefore indicated in diseases of the **right ventricle,** pulmonary and tricuspid insufficiency, and stenoses.

Fenoglio and Rosenstein agree with Waldenburg, but Schreiber's conclusions are diametrically opposed to their views. Ducrocq regards the inspiration of condensed air as **harmful** or even dangerous; Knauthe advises against the use of the apparatus in diseases of the heart, and Lazarus is even more emphatic in his condemnation of their employment. By this array of names it might appear that there can be no doubt, and that the method is to be absolutely condemned. But in the name of clinical and experimental medicine I still venture to appeal from this decision, which in some respects, at least, is too severe.

When the right heart begins to fail, inspiration of condensed air is absolutely **counterindicated** in spite of Waldenburg's assertions. It is true that the passive congestion of the lungs is diminished; that, providing each inspiration is short, arterial tension is increased and diuresis promoted; but these benefits are counterbalanced by the grave objection of a sudden afflux of blood to the already incompetent right heart. The danger is much diminished or altogether absent when the action of the right heart is normal; the method may then be employed systematically, and very good results may be obtained with **short sessions,** from inspirations of condensed air.

But it is the **peripheral circulation** rather than the central organ that is the chief point of interest in the present discussion. Since pneumotherapeutic apparatus first came into use they have been employed in the treatment of individuals presenting the type that for centuries has been regarded as indicating a **predisposition** to pulmonary tuberculosis. In this disease the germ, the bacillus, is not everything; it must be planted in a peculiar soil, and it is the **reaction of the soil** to the bacillus, rather than the cultivation of the organism itself, that demands attention. Just as certain animals, such as the rabbit and the guinea-pig, manifest a peculiar predisposition to succumb to the bacillus of Koch or to the inoculation of tuberculous material; and others, such as the mule, the goat and the dog, exhibit a great resistance to the infection; while cows and swine stand midway—so, in the same way, some human beings are much more susceptible than others to the poison of tuberculosis. When infection has actually taken place, it may either tend to spread more and more generally, or evince a tendency to become progressively limited. As most forms of medication directed solely against the bacillus have proved inefficacious and often harmful, the only plan left to us is, by a variety of procedures rather hygienic than medicinal, to modify the constitution of the individual. We do not abolish fire; but we try to build incombustible houses.*

The **phthisical habit** was known to the ancients, and there is no need to trace again the outlines of the picture so well drawn by Aretæus; it will be enough to call attention once more to the shape of the thorax and the state of the circulatory apparatus. There is usually retraction in the region of the apices (Hirtz) owing to the abnormal shortness of the first three ribs (Freund); the clavicles are horizontal and occupy

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* I paraphrase from S. Solis Cohen's Clinical Lecture at the Philadelphia Hospital, "Medical News," No. 18, p. 486, 1894.

a deeper position than in normal subjects (Aufrecht, Hanish, Jaccoud); the intermammary space is contracted (Gintrac); the section of the thorax is insufficient (Maurel); the proportion of the circumference of the thorax to the height of the body is too low (Snigerer); the angle formed by the base of the xiphoid apophysis and the cartilaginous margin of the false ribs is less obtuse; in the normal subject from 70° to 75°, in those predisposed to phthisis it is less than 60° (Charpy, Eruc). The respiratory capacity as measured with the spirometer is diminished. The heart is small (Rokitansky, Benecke, Brehmer); the arteries are contracted (Brehmer); and, in addition, it is to be especially emphasized that in all these subjects **arterial tension,** as measured by Potain's sphygmomanometer, **is lowered.** It corresponds to from 13 to 15 centimeters of mercury, while the normal pressure is 17 centimeters. This lowering of the tension is constant; it regularly follows the appearance of tuberculosis in subjects with a hereditary predisposition, or the development of malnutrition as the result of alcoholism, privation, excesses, moral, intellectual or physical overexertion, exposure to unwholesome surroundings, or after exhausting diseases, such as influenza, measles and the like. The arterial tension undergoes even greater diminution, from 13 to 10 centimeters, after the pulmonary lesions begin to develop. It is especially for the purpose of combating this lowering of the arterial tension that the employment of differential pressure apparatus is to be commended in individuals predisposed to tuberculosis. I do not believe that the diminution in arterial tension is the sole cause of that peculiar state of the organism which is usually designated the **phthisical habitus,** and which, with Jaccoud and the editor of this series, I prefer to call **hypotrophia;** but without entering into details which would here be out of place, it may be well to remind the reader that congenital or acquired stenosis of the pulmonary artery almost always terminates in phthisis, and there is authority for believing that the deficiency in the circulation characterized by arterial hypotension plays a considerable rôle in the preparation of a soil favorable for the growth of tuberculosis.*

The procedure chiefly employed is the **inspiration of condensed air,** and it is the only one that I recommend. Cross, however, fearing to induce anemia of the lungs, which would be favorable to the development of tubercles, rejects condensed air and relies altogether on the **inspiration of rarefied air.** For the same reason, and in order to

* Beddoes' good results with digitalis are worthy of recall in this connection; also the editor's observations on the liability to tuberculosis of a certain group of vasomotor ataxics.

strengthen the resistance of tissues affected with caseous degeneration, Waldenburg used **inspirations of rarefied air in combination with inspirations of condensed air;** at first with a very low pressure, $-\frac{1}{200}$ of an atmosphere, which was to be gradually increased. In the treatment of circulatory insufficiency with inspiration of condensed air, one should proceed as follows: **low pressure,** from $+\frac{1}{80}$ to $+\frac{1}{60}$ of an atmosphere, should be employed, and the sessions should be **short,** corresponding to 40 to 50 inspirations, each inspiration lasting at most three seconds. The séances should be **daily** and the entire course should last **three or four weeks.** At the end of that time it should terminate, to be resumed if necessary, and according to the indications, every two or three months.

The **effects of the treatment** are as follow: As regards the **lungs,**—the ventilation is improved, portions of the lung that are ordinarily inactive are made to functionate, the size of the thoracic cage is increased, and the inspiratory and expiratory forces are enhanced. As regards the **general condition,**—the gaseous interchanges are stimulated and the appetite often undergoes a marked improvement. The patients experience a general improvement, they have more animation, more vivacity, offer greater resistance to fatigue, and feel more cheerful. As regards the **circulation,**—arterial tension is heightened (hypotension is diminished) and tends to approach its normal degree, the assertions of Schreiber and other authors to the contrary notwithstanding; the effect is lasting and can be observed several weeks after the course of treatment has terminated. It should be emphasized once more that if the object aimed at is not to be frustrated, the patients must be instructed to take **short inspirations,** and this injunction must be repeated again and again, as they have an instinctive tendency to increase the length of the inspirations so soon as the apparatus is brought into communication with the air-passages. Inspiration of condensed air is thus **indicated** in any disease accompanied by diminished arterial tension.

Expiration into rarefied air, on the other hand, is **indicated** in all **diseases characterized by heightened arterial tension,** and especially in such affections as **diabetes** and **Bright's disease.** Increased arterial tension (**hypertension**) is the first phase of **arteriosclerosis** (Huchard); it is produced by spasm of the smaller blood-vessels. In such cases the tension attains from 20 to 26 centimeters of mercury—the normal being 17. The condition manifests itself in habitual oppression and a peculiar type of dyspnea, which is zero when the individual is at rest, and declares itself only after rapid walking or going up-stairs—

in short, dyspnea on exertion. Other symptoms consist in distressing and painful palpitation of the heart, slight precordial distress, coldness of the extremities, a feeling as if the fingers were dead, paroxysms of pallor of the integument, noises in the ears, and violent headache. To these Giovanni adds hyperemia of the bulbar conjunctiva and a peculiar form of hypertrophic rhinitis (Oettinger). The second sound of the heart is distinctly accentuated, and there is a diastolic reverberation at the aortic area. The practice advocated by Waldenburg of administering inspirations of condensed air in Bright's disease, in which there is always some heightening of arterial tension, is to be condemned. His purpose was to increase the blood-pressure, but that is already too high. Theoretically it is possible that the conjoint use of nitroglycerin with this method, or the coincident inhalation of amyl nitrite, by restricting the pressure-heightening effect of pneumotherapy to the central organ of circulation might prove advantageous. But so delicate an adjustment of antagonistic methods requires a manipulation too precise for clinical purposes.

A word more in regard to **other indications** for inspiration of condensed air. In **asphyxia** the procedure is unquestionably indicated, but unfortunately difficult of application, partly because the apparatus is rarely at hand and partly because the patient is unable to use it. In **chlorosis** arterial tension is practically normal, 15 to 17 centimeters, and I have never obtained any notable result with inspirations of condensed air except in regard to the dyspeptic troubles. Waldenburg based his recommendation of the method on the fact that chlorosis is often associated with arterial aplasia, while Kelemen attributed its beneficial action chiefly to a modification of the general condition through reflex channels. The use of the apparatus has been recommended in **diseases of the ear** in the hope of bringing about ventilation of the tympanum and effecting a massage of the drumhead; in **intestinal obstruction,** and in certain other conditions, which do not deserve special mention.

CHAPTER VIII

GENERAL AND RESPIRATORY GYMNASTICS; MECHANICAL PRESSURE METHODS

General and Respiratory Gymnastics in Pulmonary Therapeutics.—Effects of General Muscular Exercise on the Lungs. Respiratory Gymnastics—Swedish Movements; 'the Respiratory Movement.' Effects, Indications, and Counterindications of Respiratory Gymnastics. Mechanical Pressure Methods.—Passive Respiratory Exercises. Mechanical Methods of Influencing the Thorax; Application of Pressure to the Chest; Immersion of the Thorax; Schreiber's Air-cushions; Rossbach-Zoberbier Chair; Schreiber's Corset. Importance of Nasal Respiration. Indirect Insufflation as a Means of Artificial Respiration; Richardson's Double-acting Rubber Bellows; Fell's Apparatus; O'Dwyer's Tubes; Ribemont's Tube; Matas' Apparatus.

General and Respiratory Gymnastics in Pulmonary Therapeutics

Under ordinary conditions respiration takes place automatically, without the intervention of the will; the respiratory excursion is of such extent as to permit the entrance or exit of about 500 cubic centimeters (say 30 cubic inches) of air at each phase, and the respiratory frequency has the average normal rate of 18 in the minute. When, however, by reason of various circumstances, such as vitiation of the medium, increase in organic interchange, pathologic limitation of the field of hematosis, and the like, the need for oxygen is increased, respiration becomes for the time being more rapid and more profound. This **polypnea,** an act of defense on the part of the organism, likewise occurs without the intervention of the will by a sort of instinctive, or rhythmic, reflex action. Nevertheless the thought has suggested itself to physicians to utilize this normal, or rather physiologic, reaction for therapeutic purposes, by appealing to the patient's will-power, either directly or indirectly.

GENERAL GYMNASTICS

Effects of General Muscular Exercise.—All muscular exercise is followed by an augmentation of the **pulmonary ventilation,** on the mechanism of which there is no need to dwell at great length. A working muscle needs a larger quantity of oxygen, proportionate to the intensity, duration, and frequency of the contractions. As a result, there arises the necessity on the part of the lung to introduce into the organism a larger quantity of oxygen, and, consequently of air. It is not only the increased need for oxygen that necessitates greater activity on the part of the lungs during exercise; the increase in the quantity of carbon dioxid to be eliminated has the same effect—namely, an increase in the quantity of oxygen inspired and of carbon dioxid expired. The proof that this is true, that the effect is not brought about by reflex irritation,—of the respiratory center, for example,—is furnished by the experiments of Guntz and Geppert. In a dog the muscles of an extremity are isolated by ligating the efferent vessels; this done, the muscles are tetanized. Respiration is but slightly accelerated. When, however, the ligatures are removed, the blood coming from the group of tetanized muscles enters the circulation, and at once the respiratory rate is observed to redouble. Certain writers, pursuing the discussion further, have raised the question as to the identity of the substance that stimulates the respiratory centers, and it now appears that carbon dioxid should be regarded as that agent.

If there is a physiologic law well established at the present day, it is the direct relation between the functional activity and the structural development of an organ; and this law, that **function makes the organ,** not only applies to the lung, but, as will be explained later, its action in this organ is particularly rapid. For various reasons, among which may be mentioned constriction of the body by the corset, sedentary habits, and the like, most persons, even under normal conditions, utilize only a portion of the lungs during respiration. There exist, physiologically, **reserve air vesicles** which enter into activity only when there is developed what is known as air-hunger. This habitual inertia of a part of the elements of the lung, which is, we repeat, physiologic, often exceeds normal limits. In women constricted by the corset, and in persons of indolent physical habit, the slightest unaccustomed exercise induces shortness of breath. The lung is unable to satisfy the increased demand for air—air-hunger. There are, in fact, a large number of reserve air-vesicles that are rarely called into action and thereby gradually lose their power of functionating. In

some portions of the lung, which may be quite extensive, these air-vesicles develop a condition which, to use the apt expression of M. Lagrange, may be described as "losing their interest in function."

Effect of General Exercise on the Lungs.—If the augmentation of function resulting from general exercise, such as marching, running, or swimming—if the sudden activity of a large number of vesicles, caused but a temporary increase in pulmonary ventilation, the rôle of **general exercise** would not deserve a place in this study; but such is not the case. These exercises have a definite action upon the respiratory function of the lung. The experiments of Marey and Demeny, made in the military school at Joinville, have shown that at first, after exercises such as running, there is a considerable increase in the expansion of the chest and a marked slowing of the respiratory movements. At the end of six months of training the same exercises no longer induce shortness of breath and the number of respirations declines to twelve in the minute. The amplitude of the respiratory movements having increased fourfold, it is evident that the subjects thus trained respire twice as much air as they did before. In addition, the renewal of the air in the lungs * becomes more active, the coefficient of ventilation increasing at the same time as the amplitude of the inspirations.

On the other hand, M. Fernand Lagrange, the author of numerous works on the various forms of exercises, reports the case of a physician—an amateur bicyclist—who was in the habit of measuring his respiratory capacity from time to time by means of a spirometer, and who observed considerable differences in the volume of air that his lungs could accommodate, accordingly as he took his measure at a time when he was in good training, or when the demands of his practice compelled him to interrupt his riding. The augmentation during the period of training was one-third of the respiratory capacity.

This increase in the functional power of the lung manifests itself not only during exercise, but also during repose, an indication that the lung utilizes its air-vesicles to better advantage and calls into play a larger number with each respiration.

While it is true that general exercises, which increase the pulmonary respiration by increasing the elementary respiration,—that is, the interchanges that take place in the structural elements,—constitute the most perfect form of respiratory gymnastics, it must be added that they presuppose the ability to perform a greater amount of work than can always be demanded of the very patients who are most in need

* Compare the researches of Gréhant, mentioned on page 33.

of increasing the functional activity of their lungs. It is in these cases, that **local pulmonary gymnastics,** properly so called, find their greatest usefulness. The various procedures and their mode of action have been well described by M. Lagrange. (See also vol. VII of this series.)

RESPIRATORY GYMNASTICS

The **guiding principle** in this method is altogether different from that which underlies the use of general exercise for the purpose of increasing the functional activity of the lungs. No attempt is made to create a desire for air, a need for more active respiration. The patients are, in fact, already incapable of completely satisfying the normal respiratory demands, and an endeavor is therefore made to stimulate function without fatiguing the organ. The procedures employed in the **Swedish movements** are chiefly resorted to for this purpose. An attempt is made to **facilitate** either inspiration alone, or expiration alone; or, possibly, both phases of the respiratory rhythm at the same time. Among the procedures intended to increase the amplitude of inspiration, the so-called '**respiratory movement**' should be given particular prominence. This 'respiratory movement,' which is commonly employed by Swedish trainers to satisfy the air-hunger induced by the training exercises, is described as follows:

The patient raises his arms to the vertical position, at the same time taking a deep **inspiration.** He then brings the arms backward and downward, thus describing a large movement of circumduction. The result of this manœuvre is to raise the chest with the muscles that are attached to the ribs and to the humerus. These movements may be practised either in the erect or in the recumbent posture. In the latter position the resistant plane formed by the bench on which the patient reclines tends to obliterate the normal curves of the vertebral column, so that the upward movement of the ribs is greatly facilitated. In order to obtain the same extension of the spinal column in the erect posture, the patient supports himself on his toes, inclining his body backward during the entire period of inspiration.

Expiration is ordinarily passive. Under certain circumstances, however, it may require the aid of the expiratory muscles. Among the latter, the abdominal expiratory muscles are most frequently called into action. One of the procedures in the Swedish movements consists in permitting these muscles to remain inactive, and calling into play exclusively the **thoracic** expiratory muscles. This is accomplished by making it impossible for the abdominal expiratory muscles, par-

ticularly the recti, to act. The patient lies prone upon a bench and contracts the extensor muscles of the vertebral column and of the head in such a manner as to raise the head and shoulders. The recti muscles in this position being tense and unable to contract, the patient calls upon all his thoracic expiratory muscles in his efforts to make a forcible expiration.

Swedish movements yield excellent results in the treatment of **chronic emphysema.** One of the most efficacious procedures consists in passive movements having for their object the mobilization of the ribs. For this purpose direct pressure upon the ribs may be employed; or the muscles that move the ribs may be subjected to various manipulations, especially to a movement that appears exceedingly strange to the observer who witnesses it for the first time. This movement is designated in Swedish **'scrufvridning,'** which practically signifies a screwing motion. The patient being seated astride a bench to which his thighs are fixed, two attendants, grasping him by the shoulders, forcibly rotate the trunk upon its axis, alternately from right to left and from left to right. These movements are repeated a certain number of times in succession, and the shaking to which the various bones that compose the thorax are subjected, has for its object to cause one bone to play upon another and thus to mobilize, by this general shaking, the vertebrocostal articulations, upon which it would be difficult to act separately.

The manœuvre designated '*fente en arrière*' is intended to facilitate **both phases of respiration:** During inspiration the patient thrusts the chest backward in forced extension, brings the arms forcibly to the horizontal position in abduction, and carries one of his legs back to steady himself. During expiration he lowers the arms, inclines the body forward, and brings the legs in line in such a way as to favor mechanically the expulsion of air from the chest. At the same time the patient is instructed to rise on his toes during inspiration, and to flex the knees during expiration. When the vertical position is a source of fatigue to the patient, he may be made to assume the recumbent posture upon a resistant surface,—a bench, for example,—as in performing the 'respiratory movement' already described. This is to obliterate the curves of the spine and to give to the ribs a direction which better enables them to attain the maximum degree of elevation.

What is the effect of these respiratory gymnastics, and what are their indications and counterindications?

The constituent parts of the lungs, the pulmonary vesicles, being

better ventilated, do more work, their vitality rapidly increases, and they accordingly gain in **resisting power**; for it is well known that insufficient respiration predisposes to tuberculosis, and the habitual finding of the primary lesion at the apices is attributed to the deficient resistance of this region, in which respiration is most feeble.

There is always, therefore, an **indication** to ventilate the lungs, to stimulate their circulation, and to strengthen their resistance, whenever the latter has been impaired by various causes, such as a sedentary mode of life, or certain diseases of the lungs. "One appreciates," says M. Lagrange, "during convalescence from bronchopulmonary affections, the importance of increasing the amplitude of the respiration by inducing a more vigorous action of the respiratory muscles. For example, when these muscles have been maintained in a state of relative inactivity by an affection that causes shortened respiration, they tend to fall into a state of atrophy, in the same way as do the muscles in the vicinity of a diseased joint. The patient, at first compelled by his disease to restrain the respiratory movements, sometimes keeps up this habit of lessened functional activity after every physical obstruction to the expansion of the lungs has disappeared. **Convalescence from pneumonia** might often be materially shortened if the patient could be made to practise deep respiration from the beginning; thus inducing in the pulmonary vesicles the activity necessary for their nutrition. At first every organ the seat of an inflammatory disease is functionally at rest; in fact, it is to a certain degree in a condition of paresis, of inactivity, which diminishes its functional capacity, apart from any structural condition capable of inhibiting its activity. This functional inactivity is always observed in the respiratory organs; but, in addition, the disease, whatever its nature, almost always leaves behind some anatomical traces that can be made to disappear only by exercise. The lung invaded by pneumonia must resume the full measure of its normal function as early as possible, in order that the nutrition of the vesicles may recover its previous activity, which is the best preventive of chronic pneumonia and the best protection against the tubercle bacillus. In **pleurisy,** prompt return to deep and vigorous respiratory movements is the only means of preventing the formation of adhesions that threaten to bind down the lung. It also effectively prevents the thoracic walls from falling in as the effusion is absorbed. Finally, after **all inflammatory diseases** there persist disorders in the pulmonary circulation, a tendency to stasis, to passive congestion, against which no means is known to be more efficacious than extensive and profound respiratory movements. These movements act upon

the contents of the capillary vessels of the lungs like the piston of a suction-pump in accelerating the flow of blood.

"But exercise in disorders of the respiratory apparatus influences not only the contents of the chest; it often has the effect of **modifying the shape of the thoracic cage** by mobilizing the osseous parts that compose it. The indication to restore the normal shape of the thorax is often present when a chronic pulmonary affection has habituated the lung to greatly restricted movement. These **habits of restricted respiration** have permitted the costovertebral and costosternal articulations to fall into a certain degree of ankylosis, which, at the end of a number of years, renders extensive respiratory movements impossible. The functional insufficiency of the thoracic bellows is also frequently observed in the old; as age is accompanied by stiffening of the ligaments, disappearance of the synovial fluid, and ossification of the articular cartilages. There is an indication in all these cases to induce movements in the costal articulations, just as one does in the case of an ankylosed joint."

It is needless to enter into further detail in order to show the great field for exercise in the treatment of diseases of the lungs. In all the maladies of the respiratory tract the indication exists to stimulate the pulmonary functions;—in those conditions, that is to say, that are not characterized by an acute inflammatory or febrile state, or by profuse hemorrhage.

The importance of **supervised exercises,** especially in the **prophylactic treatment of tuberculosis,** has not been without recognition from early times and is recalled in many recent papers. G. R. Butler emphasizes the fact that system and persistence in pulmonary gymnastics on the part of the patient is secured by the regular attendance of the operator, without which the exercises are very apt to be neglected. Observance of the following rules is enjoined:

Hygienic dress should be insisted upon, especially in the case of female patients. Regular daily work is required, with simple exercises to be taken at home. Measurements of the thorax are made and the vital capacity ascertained by the spirometer, for purposes of comparison during the course of the treatment. The patient's general strength and pathologic condition having been carefully studied, a certain set of exercises is prescribed, so as to fulfil the indications in the given case. These indications may be: to correct deformities, depressions, and pathologic asymmetries of the thorax; to increase chest expansion and vital capacity; to secure permanently deeper breathing by training the neuromuscular apparatus to habits of ampler rhythmic action.

MECHANICAL PRESSURE METHODS

Mechanical pressure methods include manipulations practised by an **attendant,** or with the aid of **instruments;** the object being to **facilitate** by mechanical means either inspiratory expansion or expiratory retraction, or both in alternation. It is chiefly, however, for the purpose of favoring **expiration** that recourse has been had to these manipulations. The idea is not new. It is mentioned in the writings of Biermer and Gerhardt. The latter's procedure, known also as the **procedure of expression,** consists in gentle and steady manual compression of the base of the thorax and of the abdomen during expiration. These compressing movements are repeated rhythmically a certain number of times—ten, twenty, or thirty. The practice is followed by an increase in respiratory capacity; it facilitates the descent of the diaphragm, increases the amplitude of the respiratory movements, and diminishes their frequency.

Mechanical Methods of Influencing the Thorax

Under this head, we may mention **immersion,** after Simonoff, in which pressure is exerted on the thorax by the water; **manual compression** or **strapping** of healthy areas; and the practice advised by J. Solis-Cohen, of having the patient press the healthy side of the chest against a **resisting object**—as a door, a chair-back, or a leather-covered block of wood suitably mounted—during inspiration of condensed air.

The **chair of Zoberbier,** described by Rossbach, provides another most admirable means of compressing the base of the chest (Fig. 44). It is Gerhardt's method of expression, except that the hand is replaced by a sort of cuirass. The degree of compression can be regulated at will by means of levers held in the hands. This apparatus, the ingenuity of which should be sufficient to insure its success, consists of a chair with a rigid back, inclined slightly backward. Two vertical rods are attached, the one to the right, the other to the left side of the back. The rods are movable in a direction perpendicular to their axis and serve as points of attachment for two semicircular straps, one of which is wide and passes around the chest, while the other is narrower and is applied to the upper part of the abdomen. The two straps are provided with a row of hooks at their anterior extremities so that they can be laced together more or less tightly. By means of two wooden levers, bent so as to represent the arms of the chair and attached to the same rods, the straps may be tightened or

slackened at will. This apparatus has the **advantages** that it can be readily transported and that its use does not require the services

FIG. 44.—CHAIR OF ZOBERBIER.

FIG. 45.—CHAIR OF ZOBERBIER.

of an attendant. The patient himself at the moment of inspiration pushes the levers back, thus permitting free expansion of the thorax, and during expiration brings them together in front, compressing the thorax with a degree of force of which he must himself be the judge. The synchronism of the normal respiratory movements

FIG. 46.—CHAIR OF ZOBERBIER.

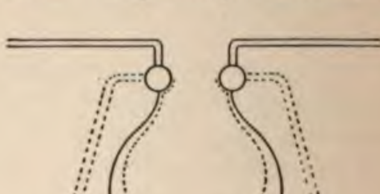

FIG. 47.—CHAIR OF ZOBERBIER, SECTIONAL VIEW.

and of the passive movements is thus admirably assured. The simplicity and usefulness of this chair are beyond doubt. It would be

desirable to know what clinical results can be obtained with its aid, but on this point the reports are, unfortunately, still quite inadequate.

The long list of apparatus constructed for the practice of **Swedish movements** includes the machines after the systems of **Zander** and **Nycanter.** Some of these machines are designed for the systematic exercise of all the respiratory muscles for the purpose of increasing their contractile power; others act either upon inspiration, by inducing passive elevation of the ribs, or upon expiration, by compressing the thoracic walls with straps.

Schreiber's Air-cushions.—Schreiber proposed the use of small rubber cushions which are attached to the thorax. They are provided with rubber tubes into which the patient blows during expiration in such a way as to exert pressure on the thorax. During inspiration the air is allowed to escape from the cushions so as not to interfere with the expansion of the chest.

Schreiber's Corset and Other Appliances.—With the appliances thus far mentioned the dilating or constricting action upon the chest is momentary; Schreiber has proposed certain devices that effect persistent constriction. His **corset** is based upon the clinical observation that, at the time of an attack, patients suffering from asthma and emphysema attempt to compress the thorax, especially the inferior portion, with their hands. The contrivance does not differ materially from an ordinary corset, except that it does not set off the waist and barely reaches below the costal margin. Above, it extends a little higher than the nipple; behind, its two halves are drawn together like those of an ordinary corset. Along the front are hooks, laced with rubber strings, so as to exert slight compression increasing from above downward. A strap passing over the shoulder on each side keeps the corset in place.

The **respiratory insufficiency** of one lung after a unilateral attack of pneumonia, bronchopneumonia, or pleurisy, results not so much from permanent structural alterations as from muscular insufficiency. The muscles, immobilized during the active stage of the disease, tend to undergo atrophy in the same way as the muscles of a limb after fracture or an attack of arthritis. When recovery ensues, the patient fails to use the side or member affected to its full capacity. Re-education is necessary to restore to the affected muscles their previous power, and for this purpose the best form of gymnastics is one that compels the side or member to resume its function. This result can be obtained by **restricting the movements** of the member **on the healthy side,** and in the case of the lung a similar plan may be pursued. The healthy

lung not being allowed to perform its function as before, the deficiency is made good by the diseased lung; at first with pain, but later with greater and greater ease. In cases of unilateral lesions, such as diminution of the respiratory capacity, pleural adhesions, muscular atrophy following pleurisy, which are so common, the following **procedure** was advised by Schreiber in 1858: During inspiration the patient applies the corresponding hand flat to the healthy side, while he raises the arm of the diseased side and places the hand upon the head. The expansion of the healthy side is thus interfered with, while that of the affected side is facilitated. In cases of unilateral pulmonary lesions Schreiber likewise makes use of a **restrictive appliance** designed to compress exclusively the healthy side. It consists of two metallic plates suitably lined, one applied in front and one behind, united by a semicircular band of steel. By means of a screw attached to this band the patient approximates the two plates at will, and thus regulates the degree of compression of the thorax. This apparatus should be worn almost continuously.

To Schreiber, then, must be awarded the merit of having called attention to a therapeutic procedure, the underlying idea of which is undoubtedly correct, and which deserves to be more widely known.

PASSIVE RESPIRATORY EXERCISES

When weakness or some other cause renders voluntary muscular effort painful or impossible, the manipulations described must be replaced by passive respiratory exercises. This method requires the services of another person, the patient timing his respirations to coincide with the movements executed by the attendant, who operates especially upon the upper extremities. The patient may be made to lie down upon a resistant surface while two attendants, grasping the upper extremities, practise **artificial respiration,** which consists of three acts: (1) Elevation and slight backward rotation of the arms, to facilitate inspiration; (2) depression of the arms along the sides of the chest and flexion of the forearms; (3) constriction of the thorax by forcible application of the arms to the chest, and pressure with the forearms laid across the lower portion of the chest.

INDIRECT INSUFFLATION AS AN AID TO ARTIFICIAL RESPIRATION

Before leaving the subject of respiratory aids it may not be out of place to give a brief account of indirect insufflation as a means of

artificial respiration. Mechanical insufflation was employed in the treatment of **asphyxia neonatorum** in the early part of the last century, when John Hunter and other English experimenters brought out various devices for its application. **Hunter's bellows** was constructed with a central partition, giving two cavities ending in a single nozle. When the bellows was opened, one of the cavities became filled through a valve with pure air from the atmosphere, while the other cavity drew in air, also through a valve, from the patient's lungs. The nozle was inserted into one nostril and the bellows was worked in the ordinary way. As the bellows collapsed, the air which had been withdrawn from the lungs was expelled into the atmosphere, and that which had been drawn from the open air was driven into the lungs. The practice, after flourishing for a time, fell into disuse as the result of its severe condemnation in 1829 at the hands of Le Roy d'Etiolles, confirmed by Dumeril and Magendie, who had been appointed by the French Academy a special committee for the purpose of investigating the question. It was shown that the sudden injection of air into the lungs was capable of causing various injuries to the organs, such as acute emphysema, rupture of the smaller bronchi, and laceration of the lung-tissue with the production of pneumothorax and collapse of the lungs This teaching, in fact, continued to dominate the minds of the profession down to a very recent period. But in 1845 the question was again ventilated by several Frenchmen, notably the obstetricians Chaussieur and Depaul, the latter of whom strenuously defended the use of insufflation in asphyxia neonatorum and devised a tube which was to be introduced directly into the larynx, the motive power driving the air being supplied by a rubber bulb. In 1867 the idea was again taken up by the practical and versatile mind of **Benjamin Ward Richardson,*** who came forward with a new **bellows** of his own devising, constructed on the same principle as Hunter's, although the author was not at that time aware of Hunter's invention. This instrument he used for a number of years, but it took up a good deal of room and was rather clumsy in its operation. He then devised the **double-acting rubber bellows** known by his name (Fig. 48), which consists of two rubber bulbs terminating in a common tube that may be called the nostril-tube. Each bulb has a capacity of four cubic inches (65.6 cubic centimeters). The valves are arranged as in Hunter's bellows, so that one bulb fills with common air and the other, after the nostril-tube has been inserted, with air from the lungs; in short, one supplies

* "Æsclepiad," vol. VII, 1890, page 211.

while the other exhausts. To the supply side is added a small, elastic bag or reservoir to prevent undue pressure on the lungs. The instrument can readily be carried in the pocket.

Up to this time indirect insufflation had been practically confined to obstetric practice; but in 1875 Blake successfully treated a case of **aconite-poisoning** by forced artificial respiration with oxygen. A small rubber tube was connected with a reservoir of condensed oxygen, the other end of the tube terminating in a small nozle which was inserted into one nostril; four hundred gallons of oxygen were used. H. C. Wood points out that this case is not strictly one of indirect insufflation, as, in addition to the force of the condensed gas in dilating the lungs, Marshall Hall's method of artificial respiration was first employed, and may have had something to do with the recovery. According to the same authority, Fell, of Buffalo, was the first physician to use **forced respiration through a tracheotomy tube** with a clear idea of its value and power in cases of poisoning.

FIG. 48.—RICHARDSON'S DOUBLE-ACTING RUBBER BELLOWS, WITH NASAL TUBE.

Fell's apparatus consists of a pair of foot-bellows by which air is forced into a receiving chamber connected with an apparatus for warming the air, between which and the tracheal tube is interposed a valve to be opened and shut by a movement of the finger. When the valve is opened, the air rushes through the chamber into the lungs and expands them; the finger is lifted, the valve shuts, the lungs retract; and so the respiration goes on. This instrument, while unquestionably efficient, is elaborate and expensive, and Wood (1890) suggested that an equally efficient and much cheaper apparatus could be made with a pair of bellows of suitable size, a few feet of rubber tubing, a face-mask, and two sizes of intubation-tubes. To enable the operator to allow any excess of air thrown by the bellows to escape, the rubber tubing should have interpolated in it a double metal tube, with lateral openings so placed that their size can be regulated by turning the outer tube.*

* From "Anesthesia," by Horatio C. Wood. "Verhandlungen des X. Internationalen Medicinischen Congresses," Berlin, 1890, vol. 1.

The following year, 1891, **O'Dwyer,** of New York, proposed a method of forced respiration which is, in effect, Wood's modification of Fell's procedure. It consists in forcing air into the lungs by means of a foot-bellows connected by rubber tubing with a set of tubes constructed to enter the larynx *per vias naturales*. The introduction of the tubes requires familiarity with the technic of intubation. The only danger attending the method, according to its author, is injury to the lungs from forcing air in and not allowing it sufficient time to escape, resulting in overdistention and rupture of the vesicles; this may be obviated by making the respirations slowly—ten to twelve a minute. Northrup, however, who reports favorable use of the instrument, states that at the author's request he tried to rupture the lungs of a child postmortem with the bellows and tubes, but failed, although he exerted all his strength.

An instrument that is extensively used in obstetric practice in

FIG. 49.—RIBEMONT'S TUBE.

France is **Ribemont's tube** (Fig. 49). It consists of a rubber bulb to which is attached a metal tube, either of nickel or silver-plated, and curved in such a way as to be easily introduced into the larynx.

The question of indirect insufflation has recently been exhaustively reviewed by Matas, of New Orleans, in a number of excellent papers from which many of the historical data in this article have been culled.* Matas's interest in the subject was aroused chiefly by the growing need in **thoracic surgery** for a trustworthy means of combating the dangers of asphyxia and of pneumothorax. He first constructed an 'experimental automatic respiratory apparatus' on the duplex principle;

* "The Surgery of the Chest," etc., "Transactions of the Louisiana State Medical Society," May 10–12, 1898; and "Annals of Surgery," vol. XXIX, 1899, pp. 408 to 434.

"Intralaryngeal Insufflation for the Relief of Acute Surgical Pneumothorax," etc., "Transactions of the Southern Surgical and Gynecological Association," November, 1899; also "Journal of the American Medical Association," June 9, 1900.

"Artificial Respiration by Direct Intralaryngeal Intubation," etc., "Transactions of the American Surgical Association," May, 1901; also "American Medicine," vol. III, No. 3, 1902, pp. 27 to 103.

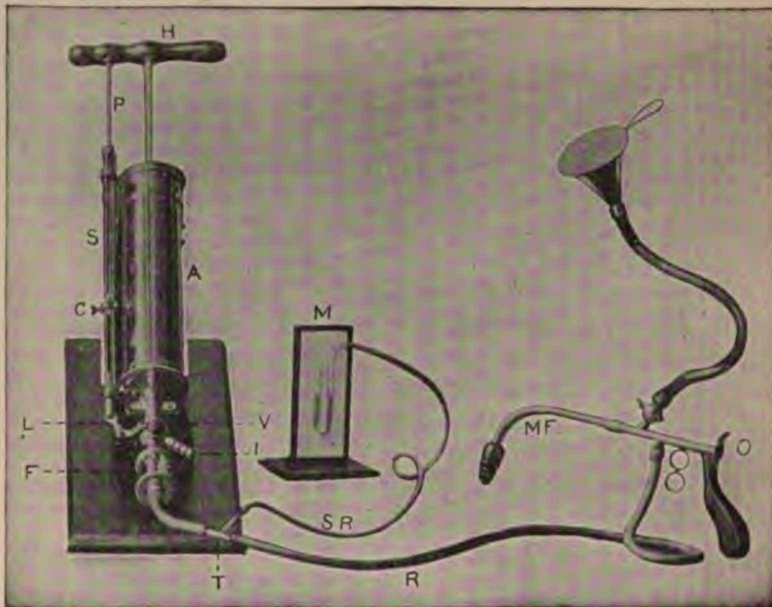

FIG. 50.—MATAS'S APPARATUS FOR ARTIFICIAL RESPIRATION (LATEST MODEL). —(*From "American Medicine."*)

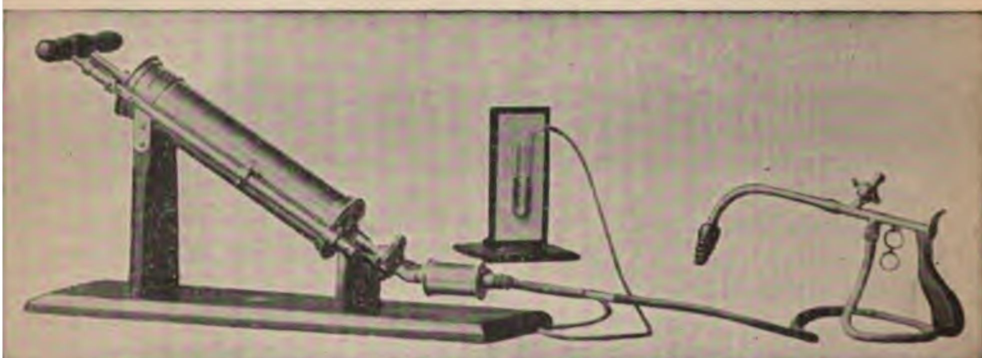

FIG. 51.—MATAS'S APPARATUS FOR ARTIFICIAL RESPIRATION (LATEST MODEL).

Pump A, on backward stroke, receives fresh or medicated air through opening I, and during forward stroke insufflates it into the lungs through opening in cut-off V. Expiration is accomplished through opening in modified O'Dwyer intubation cannula by operator removing thumb from outlet O. H, Handle common to P and the pump piston. P, Accessory piston for automatic cut-off. S, Sliding tube for automatic cut-off. C, Adjustable collar for automatic cut-off and regulating stroke. I, Inlet for fresh or medicated air. L, Compound lever for automatic cut-off. V, Valve or stopcock for automatic cut-off. F, Cylinder containing absorbent cotton for filtering air. R, Rubber tube to intubating apparatus. T, Glass T connecting manometer tube. SR, Small rubber tube connecting with manom-

with independent inspiratory and expiratory cylinders or pumps, for the purpose of studying the effects of pulmonary insufflation upon the lungs in normal and in pathologic conditions. Experiments were performed on dogs and on human cadavers, and the author arrived at the conclusion that a double inspiratory and expiratory pump is not a practical appliance for artificial respiration, on account of the damage done to the lung tissue by the aspirating force. It was found that the intrapulmonary pressure required to overcome the elastic retractility of the lungs when collapsed by the admission of air into the pleura is very slight, as had previously been shown by a number of physiologists and surgeons, and that a positive pressure of 8 millimeters of mercury is quite sufficient. Matas accordingly abandoned the aspirating cylinder altogether, and made the single insufflating cylinder the basis of his **apparatus for artificial respiration** shown in figures 50 and 51.

The question as to the advantages of **tracheotomy** over the use of a simple face-mask, or at most an intubation-tube, is of practical importance. Wood considers tracheotomy unnecessary, and believes that a simple apparatus such as he describes might even be entrusted to unskilled persons in life-saving stations, gas-works, and other places of that kind. Fell, on the other hand, while admitting that a face-mask may be sufficient in ordinary cases, believes that in protracted operations, or when it is necessary to keep up artificial respiration for a great number of hours, it is possible to breathe for the patient more easily and more thoroughly by resorting to tracheotomy. When a face-mask is used, the passage to the stomach is open and some of the air passes into the intestinal tract. Another advantage of tracheotomy appears when it is desired to eliminate the poison; the patient may be given anything by the mouth without danger of fluids entering the air-passages. In some of the cases reported by Fell artificial respiration was maintained for an astonishingly long time; in one instance for twenty hours.

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eter. MF, Modified O'Dwyer intubating cannula and stopcock attachment for chloroform anesthesia. M, Mercurial manometer, reading in millimeters to 60, pressure or vacuum. The intubation cannula differs from that of O'Dwyer, in (1) the shape of the handle, which forms the grasp of the instrument, while the thumb of the operator controls the expiratory outlet; (2) in the addition of an attachment and stopcock for a chloroform inhaler of the Trendelenburg funnel type. In this way anesthesia can be continued or interrupted while the cannula is in the larynx. So long as artificial respiration is not required, the chloroform is administered directly through the chloroform inhaler; when the pump is in operation, the anesthetic attachment is removed, the stopcock closed, and the inhaler attached to pump-inlet I.

IMPORTANCE OF NASAL RESPIRATION

The entrance of air into the lungs may be prevented by the presence of lesions in the upper air-passages. The treatment of these lesions will not occupy us here. I have, however, intentionally, brought up this subject to point out the important fact that the **manner** in which the air enters the lungs is not indifferent. As comparative anatomy proves, the nasal fossæ are the channels through which the air should enter, and their place is but imperfectly taken by the oral cavity. In the latter the air is scarcely warmed, does not become charged with moisture, and is not freed from impurities by filtration. The interchange of gases is less (Bloch), the force of inspiration and expiration is feebler than in nasal respiration (Voltolini). Deformity of the thorax is more frequent in mouth-breathers than in others; and they exhibit undue shortness of breath and a predisposition to bronchopulmonary affections.

It is important, therefore, to cite as a means of increasing the pulmonary respiration, the **procedures in which nasal is substituted for oral respiration.** These procedures are of two kinds. In some, an attempt is made to keep the nasal orifices open by means of intranasal rings and other devices that are applicable when the nostrils fail to open sufficiently during inspiration on account of weakness of their dilator muscles; as in persons who, although the nasal fossæ are open, habitually breathe through the mouth, and in cases of facial paralysis involving these muscles.

Other instruments have for their object to encourage nasal respiration by making it impossible to breathe through the mouth. To this category belongs the **contrarespirator of Guye.** It consists of a small piece of wax cloth covered with silk, which is fixed in front of the mouth in such a manner as to prevent the entrance of air. **W. R. Gordon** proposed an apparatus of celluloid which is introduced between the lips and teeth and remains in place without the necessity of securing it by means of straps. Patients whose nasal fossæ are not obstructed readily become accustomed to these instruments, and thus soon learn to resume the physiologic type of breathing. But, whatever device may be employed, one should never tire of repeating Catlin's precept to 'shut your mouth.'

PART II

INHALATION METHODS AND THERAPY

PART II

INHALATION METHODS AND THERAPY

CHAPTER I

INTRODUCTION

Definitions. General Historical Review.

Inhalation as a therapeutic procedure is commonly understood to mean the introduction into the air-passages, by means of the respiration, of air charged with medicinal substances—either for local or for constitutional effect. For some authors this definition would not be sufficiently comprehensive, and they would include in the sphere of inhalation the respiration of air, not medicated, but modified with regard to certain of its physical qualities—inhalation of cold air, of hot air, of dry air, of rarefied air, or of condensed air. The use of rarefied and of condensed air constitutes a special therapeutic method, and as such has been fully elucidated in the first part of this volume; also sufficient consideration has been given to the inhalation of air modified as to its temperature or as to its humidity. It may likewise be noted that the attempt has been made to restrict the application of the term inhalation therapy to procedures having a direct action upon the respiratory mucous membrane; but while it cannot be denied that the inhalation of such anesthetics as chloroform, ether, ethyl bromid, and the like deserves to be considered separately, we shall see how difficult it is under some conditions to distinguish the local action from the general effects induced by the inhalation.

The **medicinal substances** that can be administered by inhalation may be (*a*) **gaseous,** or, if ordinarily solid or liquid, brought into the state of **fumes** or **vapor;** (*b*) **liquid,** or, if ordinarily gaseous or solid, **dissolved** in a liquid that may be caused to penetrate into the air-passages after having been finely divided by one of a number of procedures; (*c*) **solid,** in a state of pulverization. Gases, vapors, and fumes may be allowed to **diffuse** in a certain proportion in the air of an apart-

ment—an ordinary chamber or a special cabinet—or, by some suitable contrivance may be **conveyed directly to the air-passages** from a reservoir or a generator. Non-volatile liquids and solutions of solids are usually forced by a current of air or other gas through tubes so arranged as to break them up into **sprays** or **nebulæ.** These may be propelled or inhaled directly into the respiratory tract or diffused through the atmosphere surrounding the patient. Powders are either **insufflated** or kept stirred up in a kind of **cloud** that may be drawn in with the inspired air.

We shall consider consecutively the **inhalation** of **gases,** of **vapors,** of substances **volatile** at ordinary temperature, of substances **volatilized** under the influence of heat; preparations available for **fumigation;** the **spraying** of liquids; and the **insufflation** of solid substances reduced to a powder. Finally, in a special chapter we shall review the various uses of **natural mineral waters** from the viewpoint of the method of inhalation.

General Historical Review

The therapeutic employment of inhalations dates back to the remotest antiquity; it is mentioned in the Bible and by Homer. Waldenburg has collected the most complete historical details on the subject. Inhalation-therapy was common in Hippocratic and Galenic medicine, but until the eighteenth century volatile agents or the fumes obtained by combustion from certain substances were chiefly employed. Celsus recommended the use of steam in the treatment of ulceration of the pharynx. The inhalation of sulphurous vapors set free in certain depressions about volcanoes (Vesuvius, Etna) was recommended and largely practised in the Roman era. The Arabians, particularly Rhazes, fol owed in this, as in many other matters, the precepts of Hippocrates, and attributed great value to balsamic fumigations in the treatment of diseases of the lungs. Bennett in the seventeenth century was the first to make a distinction between **dry** and **moist** fumigation, the latter being attained by the respiration of the vapor of water impregnated with volatile aromatic substances. In connection with this classification we may mention that which is found still in certain modern works: namely, balsamic, emollient, sulphurous inhalations, etc.

Throughout what may be termed the **first period,** which terminated only with the discovery, late in the eighteenth century, of the gases that enter into the composition of atmospheric air, and the advances in chemistry that followed the memorable labors of Priestley, of Scheele,

and especially of Lavoisier, inhalation as a therapeutic method suffered many vicissitudes in professional esteem and use—now praised and resorted to without reason; again, with equal unreason, condemned and well-nigh given up. Nevertheless even during the times in which it was abandoned officially, the measure retained its popular vogue, and it is one of the procedures of empiric medicine that has been employed with greatest faith.

It is perhaps not very difficult to discern the reason for this faith, or at least to find its justification. In the first place, the influence on the development of diseases of the air-passages of chemical, and especially of physical changes in the atmosphere, suggests as a means of relief for the malady some modification in the constitution of the air; and, besides, up to a recent date authors of the highest authority have boldly proclaimed the opinion that the only effective remedy for thoracic affections, and for tuberculosis in particular (Mascagni), is one that reaches the lungs through the agency of the respiration. We need not recall at this time the interest excited by the communication of von Rokitansky announcing that he had found in inhalations of a solution of sodium benzoate the specific for tuberculosis, and even for pulmonary phthisis in the stage of excavation. During a more recent period were we in France not carried away by a veritable infatuation, when inhalation of hydrofluoric acid was recommended for the same purpose? The immediate result of such unjustifiable enthusiasm was to place the method of inhalation in the first rank and to give rise to a foolish rivalry among the various hydro-mineral resorts, each of which vaunted its inhalation chamber. Then, when the facts came to be better appreciated, the resulting disappointment of baseless hope led, by a natural revulsion of feeling, to undeserved condemnation of the method.

I have thus endeavored at the outset to state precisely, if briefly, the causes of the alternations of favor and disfavor through which the method of inhalation has passed, because these factors persist at the present day, and will persist so long as the scientific spirit is not strong enough to permit the avoidance, even in medicine, of waves of undue enthusiasm and of systematic negation.

I shall not try to give a complete history of the successful researches of the nineteenth century. The discovery of new substances isolated or prepared synthetically by chemists has singularly enlarged the one-time narrow limits of inhalation as a therapeutic resource. Reference in the course of our exposition of its practice to some of the numerous publications that have appeared in all countries will serve

to show most clearly the position now occupied by this method; but I should do real injustice did I fail to mention the work of Sales-Girons (1861) on the use of liquids in the form of sprays. A large part of our space will be devoted to the applications of the discoveries and inventions that this investigator authoritatively naturalized in medicine.

Among works of similar character on the technic and the therapeutic employment of inhalation we may mention first that of Martin Solon —*Atmiatrie Pulmonaire*—published in 1834, a contribution that has been too much ignored and in which will be found a description of most of the applications of inhalation; it contains a detailed account of the medicaments employed and of the procedures practised *; as well as a discussion of their physiologic effects. Among later publications that have served to establish inhalation upon a firm basis of scientific method and clinical experience we cannot ignore those of Demarquay in France (1866); J. Solis-Cohen in America (1867 and 1876); and Waldenburg in Germany (1872).

* "Gazette médicale," tome II, No. 12, page 177, Paris, 1834.

CHAPTER II

INHALATION OF GASES

Inhalation of Gases—General Methods and Apparatus; Absorption of Gases. Special Agents—Oxygen; Ozone; Nitrogen; Hydrogen; Chlorin; Carbon Dioxid; Illuminating Gas; Hydrogen Sulphid; Sulphurous Acid; Hydrofluoric Acid; Formaldehyde; Ammonia; Nitrogen Monoxid.

General Methods and Apparatus

Gases are usually described, in accordance with their lack or possession of irritating effect upon the air-passages, as **respirable** or **irrespirable.** All pure gases, if inhaled in sufficient quantity, or for a sufficient period,—even if respirable,—are **toxic;** either indirectly by exclusion of oxygen—as in the case of nitrogen and, in large degree, of carbon dioxid—or directly, by action on the blood or tissues, as in the case of carbon monoxid, or of oxygen itself. In medicine, therefore, gaseous inhalations are administered for **limited periods,** and the agent used is, as a rule, **much diluted** with atmospheric air, or sometimes with oxygen.

Beddoes long ago pointed out, as before him both Bacon and Bennett had suggested, the best **method** for the therapeutic employment of gases; namely, by the production of a 'factitious atmosphere' in which the patient might remain for several hours continuously. Thus the air of an ordinary apartment or of a good-sized pneumatic chamber may be charged with the medicinal gas in a definite proportion—which, for such prolonged inhalation, would usually be small. As ventilation is to be kept up—unless the apartment be so large that the products of respiration will not accumulate in objectionable proportion during the patient's stay in it—a mechanism must be provided for the continuous introduction of a known and correct quantity of the agent employed. This method, while practicable, is troublesome, and hence has not come into general use. It is less difficult, but also less pleasant, to seat the patient in a small cabinet provided with the medicinal atmosphere. As the confinement cannot be prolonged, it is also less effective, except for agents to which a short exposure is desirable.

Hence the general practice is to prepare a certain quantity of the gaseous mixture to be respired—usually with the largest proportion

FIG. 52.—*a*, GLASS MASK WITH PNEUMATIC CUSHION. *b*, METALLIC VALVED MASK WITH PNEUMATIC CUSHION.

FIG. 53.—SOFT RUBBER MASK WITH INFLATABLE CUSHION, EXPIRATION VALVE AND AIR-REGULATING ATTACHMENT.

of the active agent tolerated or safe—and to have the patient inspire this by means of a suitable apparatus, exhalation being made into the atmosphere.

For such inhalations a **gasometer** (Fig. 55) in which to hold the mixture of gases for respiration is desirable; and, as already stated, it was for this purpose that the instrument in question was devised by James Watt. A **rubber bag** (balloon) furnished with a suitable stopcock may, however, take its place as a reservoir; or the gaseous mixture—or a gas to be mixed with air—may be drawn from **metallic cylinders** in which it is stored under pressure (Fig. 56); or the gas may be **evolved extemporaneously** at the moment of inhalation. A **filter** is sometimes needed and a **Woulff bottle,** or, at all events, a wash-bottle, is practically

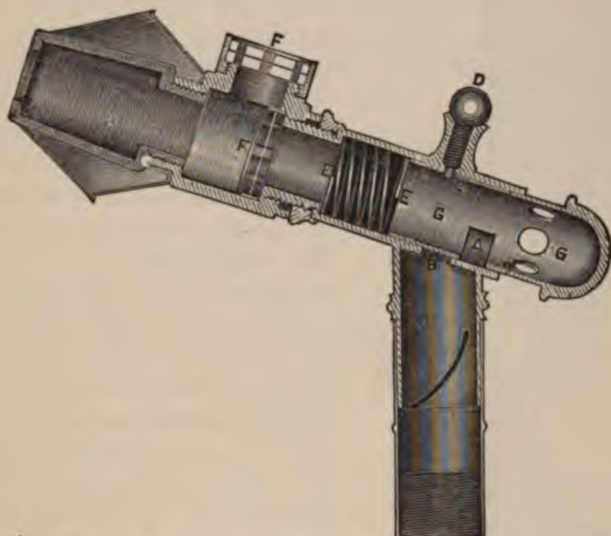

FIG. 54.—VALVED TUBE TO REGULATE ADMISSION OF AIR TO MASK, FOR USE ESPECIALLY WITH NITROUS OXID.

indispensable. Not only is it necessary to wash the gas to prevent dust and impurities from reaching the lungs, but, also, one is better able to watch the patient's method of breathing, to determine approximately the quantity of medicinal gas taken in at each inspiration, and to regulate these factors. Indeed, it is only thus that one can be sure that the patient is actually inhaling the gas desired. Sometimes a **heating** or a **cooling device** is employed, but, as a rule, the gaseous inhalation is made at the temperature of the apartment. It is, of

course, necessary to be careful as to the **cleanliness** and bacteriologic purity of the apparatus; and to watch all tubes, valves, and other parts, that no obstruction may occur. Nor should one be satisfied with the mere cleansing of the terminal of the apparatus with which the patient comes in direct contact; a **separate attachment** should be provided for each person.

FIG. 55.—S. S. WHITE GASOMETER IN CONNECTION WITH CYLINDER OF LIQUEFIED NITROUS OXID, WITH MASK HAVING VALVE FOR ADMISSION OF AIR.

The terminal may consist of a **mask,** a **mouthpiece,** or a **nozle.** The masks may be of spun metal, or of hard rubber,—with pneumatic cushions,—of soft rubber, or of glass (Fig. 52). Some have expiration valves (Fig. 52, *b* and Fig. 53), some have both inspiration and expiration valves, and some are without valves. Some are so arranged as to permit the introduction of a definite or indefinite quantity of air together with the medicinal gas (Fig. 54). The mouthpieces may be cylindrical or flattened, the nosepieces cylindrical or olive-shaped. They may be of metal, hard rubber, ivory, wood, bone, or glass; the latter being preferable on the score of cleanliness. When inspiration is made through the mouth, expiration may be made through the nose, or the mouthpiece may be removed from between the lips, and expiration made through the mouth.

If the inhaling apparatus be so adjusted that the gas is in static equilibrium with the atmosphere, the effort of inspiration, if correctly made, will suffice to cause it to enter the air-passages. When an ordinary rubber bag (holding from one to twelve gallons) is employed as a reservoir, the flow of gas may be assisted, if necessary, by **pressure** of the patient's arm as he sits at

the inhaling table, or an attendant may make the pressure. As the bag empties it is to be rolled up, to keep the gas-containing portion distended. When large gas-bags are used, pressure is made by means of weights.

Absorption of Gases

That gas actually penetrates into the air-passages cannot be questioned. Nevertheless it is necessary for us to note at once that it is not possible to continue beyond a certain brief time, from two to three minutes on the average, the respiration of a gaseous mixture not containing oxygen. In addition, we should always strive, if possible, to secure with the gas inhaled a respirable mixture, either by adding air in definite quantity to the stored gas, or admitting it with the current of gas inhaled. With this precaution one may respire an indifferent gas for a sufficiently long time to produce therapeutic effects, without provoking any defensive action on the part of the mucous membrane. In this way, moreover, it is possible to attenuate remarkably the irritant effects of most of the gases regarded as irrespirable. These conditions explain the advantage in general of the use of a mask in the inhalation of gas. A proposition that has been made to convey the gas to the center of a plate placed in the mouth in front of the teeth, thus permitting air to enter during inspiration, on either side of the plate, and expiration to be made through the nose, appears to offer for medicinal gases no special advantage over the careful use of an ordinary mouthpiece around which the lips are not too tightly closed; while for anesthetic purposes, as with nitrous oxid, the valved masks permitting accurate regulation of the mixture with atmospheric air or oxygen are much to be preferred.

OXYGEN

Oxygen enters into the composition of most substances that exist within the organism; it plays a primary rôle not only in the respiratory phenomena, in the processes of combustion productive of animal heat, but also in all the processes concerned in the nutrition of the tissues. The quantity of oxygen absorbed in respiration, representing almost $\frac{7}{10}$ of the oxygen introduced into the organism, has been estimated at about 750 grams a day. The important part taken by this gas in the nutritive processes suggests at first view that by increasing its proportion in the inspired air, or even by having it inspired in a pure state, one could exert a profound influence upon the organism, such as might be of real efficacy in the presence of certain pathologic con-

ditions; in fact, oxygen was employed in therapeutics before its physiologic action was known. Recommended with enthusiasm for asthma, for asphyxia, and for chlorosis by Jurine, by Chaussiez, by Beddoes, who made a profound study of it, by Fourcroy, by Birch, the inhalation of oxygen was later practically abandoned for many years. In the course of the last three decades, however, it has again come into favor, and there is, indeed, danger that it may be employed in conditions in which it is not only useless but harmful. I shall endeavor to point out its legitimate uses and its limitations.

Physiologic Action

The observations of physiologists are far from affording powerful arguments in favor of the therapeutic utility of the inhalation of oxygen. It appears from the experiments of Paul Bert that if an animal be made to breathe in an atmosphere that is not renewed, and if care be taken to remove the carbon dioxid so as to maintain the normal proportions of this gas in the atmosphere, death will take place only when the oxygen is almost entirely exhausted (2 per cent., 1 per cent., or even 0.5 per cent.). **Absorption** thus appears to be independent of the proportion of oxygen contained in the medium respired by the animal. This is shown by the experiments of Lavoisier and Seguin, and especially by those of Regnault and Reiset and of Fredericq. Spallanzani, Allier, and Pepis have expressed a contrary opinion. The experiments of Paul Bert have more nearly settled the question, and show that the absorption of oxygen increases in proportion to the amount of oxygen contained in the medium respired until it falls below 42 per cent., after which absorption diminishes. By a different procedure Quinquaud found that if an animal be made to inhale oxygen, hyperoxidation of the blood results. From a number of observations Speck concluded that the increase in the proportion of oxygen contained in the inspired air increases the absorption, but only at first—a circumstance that would explain, without doubt, the contradictory results of others. Loewy independently reached conclusions opposed to those of Paul Bert; instead of an increase in the absorption in consequence of prolonged respiration in a medium containing as much as 40 per cent. of oxygen, he noted a diminution. It must be remembered that the physico-chemical conditions of respiration in a normal animal do not permit of an unlimited increase in absorption of oxygen; the maximum being precisely fixed by the quantity of hemoglobin present in the circulating blood. On the other hand, if we pass from the domain of physiology to that of pathology, there is no doubt that in most cases

of deficient oxygen absorption it is not necessary to suppose that the supply of oxygen is insufficient, the want of oxygenation being readily explained by the lesion itself, which restricts the field or the power of absorption. The morbid alterations may affect the lung, or the red blood-cells, and in the latter event may be a diminution of their number, or a pathologic modification of their constitution and consequently of their absorbing capacity. However this may be, inhalations of oxygen are still too frequently recommended without adequate consideration of their pharmaco-dynamic action and their therapeutic indications.

If, in the normal state, following the procedure commonly employed, the pure oxygen contained in a rubber bag be inhaled, there will not be produced in general either appreciable stimulation of respiratory activity or general excitation. However, Aune, the author of a most interesting thesis submitted to the Paris faculty in 1880, relates that he observed in himself an agreeable intoxication together with a sensation of numbness in the extremities of the fingers and toes. In an atmosphere of pure oxygen the conditions are somewhat different. Gubler and Labbé, who observed with care the symptoms under such conditions, noted, at the end of about a minute, slight vertigo, and a transitory intoxication, disappearing as soon as the subject returns to the open air. The respiratory movements and the pulse diminish but little in frequency and there is a pronounced feeling of well-being. After the séance the individual may remain a long time without breathing (Gubler), without doubt on account of the hyper-oxygenation of the blood.

Aune has noted a slight increase in the number of red blood-corpuscles and of hematoblasts. He attributes the increase in the number of erythrocytes to the fact that they become more resistant. It would be more plausible to suppose that there is an excitation of the normal hematopoiesis, an excitation that gives rise to hematoblastic activity; but this need not concern us now, for, as a matter of fact, the observations of Aune have not as yet been sufficiently confirmed by others.

The **pulse** of the dog when submitted to daily inhalations of oxygen becomes diminished in frequency (Quinquaud, Loewy). Aune found in himself a notable acceleration. A similar contradiction exists as to the **temperature,** which, according to Aune rises, and according to Quinquaud falls.

A study of the **urine** should permit of a conclusion as to the influence of oxygen on the **nutrition**; and accordingly this has been the subject of a number of investigations. The quantity of urine remains un-

changed, as does also that of urea, of uric acid, of phosphoric acid, and of the chlorids (Aune). Quinquaud determined a diminution in the carbon dioxid, and believes, as a result of his experiments upon a woman, that there is a retardation of organic combustion. A. Robin observed increased excretion of urea under the influence of oxygen. Kollmann, in 1865, observed independently a decrease in the amount of uric acid. Krafft, at the end of a series of inhalations of oxygen extending over eight days, noted a slight diminution in the quantity of nitrogen, but no modification in the elimination of urea and uric acid. Eckardt observed a diminution in the amount of uric acid and the disappearance of albumin in an albuminuric subject. Ritter attributes to inhalation of oxygen an influence upon inorganic oxidation, having observed an increase in the acidity of the urine and the presence in greater quantity of products representing more complete oxidation. **Muscular power** tends rather to become diminished. With reference to the **digestive tract,** Aune noted an increase in the appetite, and the observation has been verified by Albrecht. The latter agrees with the opinion expressed by Ch. Richet that the secretion of the acid gastric juice is an oxidation-phenomenon, brought about by the influence of the oxygen given up by the blood.

Oxygen inhaled **under pressure** greater than that of the atmosphere gives rise to phenomena that have been considered in connection with pneumotherapy.

The editor of this series has, in an encyclopedic article, **summarized** the action of oxygen as follows:

Inhaled undiluted, oxygen causes subjectively a sensation of warmth in the mouth and air-passages, and there seems to be lightness and ease in respiration, sometimes in mental processes likewise. Objectively, there is acceleration of the pulse with increased hardness, indicating a rise of blood-pressure from increased force of the cardiac action. Warmth of the cutaneous surface is usually observed. The visible mucous membranes, sometimes the cheeks as well, are heightened in their red color, and in case of cyanosis are restored to their normal hue. Sometimes there is increased moisture of the skin. The respirations are usually increased in frequency at first, but subsequently the depth increases and the number diminishes. If the inhalation continues for too long a time, violent mental and physical excitement, with rise of temperature, may be produced. This is marked in small animals, such as the mouse, guinea-pig, cat, and dog, kept in an atmos- ... diluted oxygen. In such animals death may occur in a ... d all the viscera be found congested or inflamed. Such

effects, however, are not common in human beings inhaling oxygen for the comparatively brief periods usual in therapeutic administration, except in the case of subjects of pulmonary tuberculosis, in whom, as Beddoes pointed out, increased inflammation and febrile movement may result. In Sir B. W. Richardson's studies of the effects of oxygen upon lower animals, the process of manufacture of the gas used seemed to make a difference, probably due to the admixture of ozone in some cases. Temperature exerted a marked influence, oxygen at 20° F. or 125° F. becoming practically a narcotic poison. The range of temperature most favorable to life was from 55° to 90° F. Between these temperatures and the extremes before noted, an anesthetic effect was produced. The degree of concentration of oxygen in the factitious atmosphere was also found to modify the effect. Life could be sustained longer in an unchanged atmosphere of diluted oxygen than in the pure gas, the most favorable mixture being that found in ordinary air—one part of oxygen to four parts of nitrogen. Important differences were noted in the reactions to oxygen of cold-blooded and of warm-blooded animals, the former being perturbed but slightly. Among mammals, different species were affected differently, the rabbit, for example, resisting the pyretic and phlogistic influences. Perhaps the most striking result obtained by Richardson is that dependent upon the difference in the effect of breathing a still atmosphere of pure oxygen and that of breathing pure oxygen in current. In the former case, after the stage of excitement, narcosis and death ensue in a few hours; in the latter case the animal continues to live for days. That death is not due to accumulation of carbon dioxid is proved by making provision to absorb this gas; and even when all other products of respiration are removed, the oxygen that has been breathed and rebreathed for some time, while still able to support combustion, is unable to support life. 'Devitalizing oxygen' may, however, be made 'vitalizing' again by the effect of an electric discharge (see Ozone). These facts indicate a source of danger in crowding and lack of ventilation apart from those commonly recognized.

The **physiologic effects** produced on man by medicinal inhalations of oxygen are usually transient; but after repeated inhalations in cases of **disease** certain **permanent effects** begin to be manifest. Appetite becomes greater and there is increased ingestion of food, with consequent gain in weight. The number of red corpuscles in the blood and the relative as well as the absolute hemoglobin percentage are sometimes augmented. The excretion of uric acid diminishes and that of urea probably increases; observations upon the urinary excretions are, however, conflicting.

Applied to the **unbroken skin**, oxygen is practically without effect, perhaps increasing the exhalation of carbon dioxid. When, however, the gas is [illegible] in contact with **wounds** or **ulcerated surfaces**, [illegible] immediate and painful irritation, accompanied with increased [illegible] of abundant fluid exudation; granulations increase, and [illegible] long continued, become ecchymotic and lose [illegible]. Oxygen may be introduced beneath the [illegible] in loose combination, as hydrogen dioxid. [illegible] it may be injected into the [illegible] through the chest-wall, and it is said that with [illegible] injected into the veins. It has been [illegible] through a suitable tube. However introduced, [illegible] its effects primarily upon the tissues [illegible] the organism as a whole.

[illegible] **pathologic conditions**.—[illegible] specific effects have been alleged [illegible] has been said to diminish the production [illegible] **diabetes** [illegible] capable of arresting diabetic [illegible] products that would otherwise form diacetic [illegible]

[illegible] Indications

[illegible] **counterindications** that are deduced from the [illegible] it is quite difficult to point [illegible] necessary with Waldenburg. [illegible] that useful [illegible] admit with Nothnagel [illegible] the best method of administering [illegible] to breathe air that is pure and [illegible] exaggerated, as is likewise [illegible] whether inhalations of oxygen [illegible] suggest [illegible] With Hayem I am con-[illegible] definite therapeutic value. [illegible] sufficient to explain the facts, the [illegible] is to be sought else-[illegible] but not to demand an [illegible] has been used in a great variety [illegible] that the justification of sufficiently [illegible]. When, however, it is desired to stimulate oxidation [illegible] in which pulmonary gaseous exchange [illegible] amount of air that reaches [illegible] lungs proves insufficient [illegible] of a lesion of the air-passages, [illegible] the lungs themselves, the absorbing power of the hemoglobin

remaining intact; and at times for the purpose of influencing certain **gastric states,** oxygen may rationally be used on the basis of empiric knowledge.

Mode of Employment

The use of chambers into which is introduced a current of pure oxygen instead of air would appear to be *à priori* the most effective method. This procedure is but little employed. A **portable apparatus** consisting of a rubber reservoir containing oxygen is more generally used in France. The oxygen in escaping from the bag passes through one or more wash-bottles. Aspiration being made by the mouth, the oxygen penetrates with each inspiration into the air-passages, more or less freely mixed with air as the lips are more or less widely parted about the mouthpiece. A better method is the use of portable apparatus permitting direct respiration of oxygen under pressure, or of a gaseous mixture containing a definite percentage of oxygen; the diluent may be air, nitrogen, nitrous oxid, carbon dioxid, or other gas, according to the effect desired.

In the United States certain manufacturers devote special attention to the supply for medicinal purposes of purified oxygen, undiluted, or mixed with nitrogen monoxid in various proportions, and stored under pressure in steel cylinders. One very convenient form is shown in the annexed illustration (Fig. 56); 40 gallons of oxygen under 1800 pounds pressure are contained in a cylinder 3 inches in diameter, less than 13 inches in height, and weighing but 11 pounds. The gas will have a purity of 95 or 96 per cent., being diluted by the small quantity of air in the container. Mounted on the cylinder are a rubber bag of one gallon capacity, and a wash-bottle—so arranged that the gas passes first to the bag and then through the wash-bottle to the patient.

If it be desired to **measure the quantity** of oxygen administered, the bag may be filled, emptied by the patient's efforts of inspiration—or, if these be too feeble, by manual pressure of the attendant;—then refilled, again emptied, and so on. If, however, the patient be very **weak,** or **unconscious,** or **delirious,** it is best to use the rubber bag simply as a pressure regulator, and to allow the oxygen to pass through it **continuously** into and out of the wash-bottle. This can readily be managed by adjusting the screw-valve that controls the outflow from the cylinder. A manometer may be attached, but usually the pressure and the speed of delivery can be estimated with sufficient approximation by watching the passage of the bubbles through the wash-water. A gentle, steady stream that does not cause appreciable splashing, and

it may sometimes save life. When one desires to administer oxygen under a known and predetermined **pressure,** the gas may be drawn from a gasometer, or a weighted gas-bag.

Some physicians prefer **recently evolved** or even **nascent oxygen,** believing it thus to be more active chemically and therapeutically. For quick use, Dr. Wallian has arranged a cylindrical retort of steel, a package of chemicals (four parts of potassium chlorate and one part of manganese dioxid, finely pulverized and mixed intimately), a lamp, stand, and several wash-bottles, in a box of convenient size for carriage. The gas as evolved from the retort passes through a solution of potassium hydroxid (0.5 per cent.), then through a solution of silver nitrate (0.5 per cent.), then through distilled water. It is collected in a rubber balloon, whence, through a larger wash-bottle—in which, if desired, aromatic substances may be placed—it is inhaled by the patient. Any available retort may be utilized similarly. In the extemporaneous production of oxygen by this method, purity of the ingredients is essential, not only to avoid contamination of the product, but to prevent accident. It is also necessary to wash the gas thoroughly, as just described, in order to remove any traces of chlorin or free acid that may be given off.

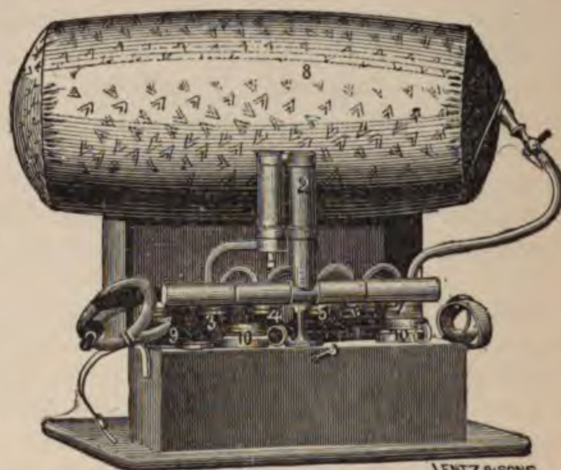

FIG. 57.—WALLIAN'S OXYGEN GENERATOR SET UP FOR USE.

Another **method of preparing** oxygen has come into vogue within recent years, since pure hydrogen dioxid has been more readily obtained in the shops. A solution of potassium permanganate—8 grains to the ounce—is allowed to drip slowly into a solution of hydrogen dioxid contained in a Woulff bottle or other suitable receptacle furnished with two openings, one for the ingress, and one for the egress tube; the latter, to which the mouthpiece is attached, not being allowed to pass more than about an inch below the stopper. A plan even more convenient is to introduce into a long-necked flask of about 4 ounces

capacity, stopped with rubber and furnished with an air-tube and mouthpiece, 2 fluidounces of the official solution of hydrogen dioxid, and to pour upon it an equal quantity of boiling water; to this should then be added a half-teaspoonful of washing soda (sodium carbonate) as free from lumps as possible. Oxygen will be disengaged and bubble slowly through the fluid.

Sir Benjamin Ward Richardson believed what he termed **'ethereal oxygen'** to be one of the most useful of his many contributions to therapeutic resources. In a two-necked Woulff bottle, one neck of which was furnished with a delivery-tube and a valved mouthpiece, he placed 2 fluidounces or more of 'ozonic ether' (which is a '30 volume' solution of hydrogen dioxid in ether), poured through a funnel in the other opening, 1 fluidounce of a solution of potassium permanganate (8 grains to the ounce), and then corked that opening while the patient inhaled ether and oxygen through the mouthpiece. He also demonstrated the usefulness of oxygen as a **carrier** of many other vapors—as ethylene, chloroform, methylene, methylal, amyl nitrite, ammonia, iodin, bromin, benzoin, turpentine, and volatile oils. The oxygen may be freshly evolved from hydrogen dioxid in a flask containing the volatile substance on or in the dioxid solution, or a gentle current of oxygen from any convenient reservoir may be passed through the medicated solution into the inhaler. When water is not admissible, the volatile substance—say iodin or turpentine—is placed in a good-sized flask with a double neck, and the oxygen simply flows over it on its way to the inhaler. Another method is to charge an elastic receiver with oxygen that has passed over the volatile medicament, and to have the patient inhale directly from this a fixed quantity. Clover's (chloroform) inhaling bag and the cellulite mouthpiece of Richardson are the best appliances for use in this manner.

What is the **quantity** of oxygen necessary for each inhalation-séance? How **often** should such séances be repeated in the course of twenty-four hours? According to Quinquaud, it will be preferable to employ a mixture composed of one-third pure oxygen and two-thirds air. With the technic that we have indicated as that usual in France (page 303), it is about under such conditions that inhalation is practised. Each inhalation-séance should last from twenty to thirty minutes.

According to Quinquaud, the inhalation of from 5 to 6 liters of oxygen repeated three or four times a day is without effect: this is the only adverse opinion that needs to be discussed. Absolutely sound when it is purposed to modify the general nutrition, the state-

ment is incorrect when applied to cases in which it is desired to relieve the effects of **temporary restriction of the respiratory surface.**

Special Therapeutics

The conditions in which inhalations of oxygen have been employed with varying success are as numerous as they are varied. We may pass them rapidly in review, confining ourselves exclusively to observations sufficiently confirmed to deserve serious consideration.

Disorders of Metabolism.—The idea that inhalations of oxygen are capable of modifying the rapidity and the character of organic combustion has led many practitioners to employ these inhalations in the most diverse disorders of nutrition.

In **diabetes,** notwithstanding the facts put forward by Rollo, Scelles, Yvon, and Casorati, the observations of Weber, of Lécorché and Talamon have established the absolute uselessness of oxygen administered for the purpose of increasing the combustion of the sugar contained in the blood. Notwithstanding the diminution clearly observed in one case in the amount of uric acid excreted, Kollman denies any value to oxygen in the treatment of **gout.** Oxygen has been recommended also for **obesity** (Beddoes), for **lymphatism,** for **rachitis,** for **carcinoma** (Gutteridge).

Disorders of the Blood.—Its employment in the treatment of **chlorosis** (Beddoes, Haller) is still justifiable. It is true that in this affection the pulmonary tissue is intact and permits the gaseous interchange to take place, while it is the alteration in the erythrocytes that limits the absorption of oxygen; and it is precisely in such conditions that one would think last of all of employing oxygen—the quantity of this gas contained in the air being more than sufficient. Nevertheless, Hayem, who has studied with care the effect of the inhalations, has seen the number of red corpuscles increase under their influence. As the principal effect of the oxygen is, under such circumstances, expended upon the digestive functions, it is without doubt in an indirect way that this restoration of the blood is effected. Sticker has recently extolled inhalations of oxygen in cases of **leukemia,** but his results have not been confirmed.

The employment of oxygen in cases of **post-hemorrhagic anemia** (Beddoes, Thierry, Megg) seems both useless and unjustifiable; as also in cases of grave anemia (Honigmann, Koster); although it is only fair to say in this connection that DaCosta saw at least temporary good results from its use in some cases of pernicious anemia.

In **premature children** and in those suffering from **congenital debility,**

inhalations of oxygen have yielded most encouraging results in the hands of Tarnier, of Bonnaire, of Miss Landais, and others.

Infectious Diseases.—In certain acute and chronic infections, such as **malaria** (Beddoes, Foley, Hill), **scorbutus** (Beddoes, Trauttner), **scarlet fever** (Francis), **rubeola** (Smith), **syphilis** (Birch), etc., oxygen has been lauded, but experience has established its inutility. Employed by numerous clinicians in **typhoid fever** (Foley, Beddoes, Fanta, Ingenhanz) oxygen was believed to have an especial effect upon the prostration and in hastening retarded convalescence (Dureau). S. Solis Cohen has indeed observed good results from oxygen inhalations conjoined with saline infusions in cases of undue prolongation of typhoid fever—probably due to mixed or sequential infection—as also in hastening convalescence in patients exhausted by a severe attack. Lichtenstein, Nicol, Créquy have extolled inhalations of oxygen in the period of asphyxia or collapse in **Asiatic cholera.** Sales-Girons, after De Smytten (1832), and Harvey (1853) recommended them at the onset of the disease, but according to Bernutz the therapeutic result is absolutely negative. In various forms of **septic disease,** oxygen inhalations have been advised, and seem to be useful at times in combating asthenia and toxemia.

Intoxications.—The employment of oxygen in the treatment of various **drug-intoxications** and **toxemias of disease** appears *à priori* more logical; whenever, at least, the number of red corpuscles remains sufficient and their power of absorption is only temporarily modified. These restrictions permit a comprehension of the inutility of the method in cases of intoxication with carbon monoxid, or with illuminating gas containing a large proportion of this agent. It has been recommended in **diabetic** and **uremic coma;** for the treatment of **poisoning** with **chloral** (Smith), **opium** (Beddoes, Constantin Paul), **alcohol, hydrocyanic acid** (Preyer), etc.; and to hasten the return to consciousness after **chloroform** or **ether anesthesia,** etc. (Jackson, J. Solis-Cohen, Ducroy, Erichsen, and others); as well as to promote recovery in case of dangerous **narcosis** following the inhalation of these agents.

Oxygen inhalations are frequently used by American surgeons **in conjunction with ether or chloroform,** as a **prophylactic** measure against collapse or to avert or mitigate the unpleasant concomitants or sequels of anesthesia. Cole, of New York (1895), appears to have been the first to practice the method systematically. At first advocated in every case, it is now—whether wisely or unwisely—more restricted. The special indications are a severe and protracted operation, a cardiac r the general depraved condition of the patient. Various

methods are employed. In one process the ether or chloroform is placed in a wash-bottle through which oxygen passes, the delivery-tube being attached to a valved mask placed over the patient's mouth

FIG. 58.—APPARATUS FOR THE CONJOINED ADMINISTRATION OF OXYGEN AND ETHER. —(*Howard Hospital, Philadelphia.*)

and nose; in another the ether cone or chloroform mask is removed at short intervals to give place to the oxygen tube, the color of the patient's face affording a ready index for the application of the gas.

Perhaps the **best method** is that shown in the illustration (Fig. 58); the delivery-tube from the wash-bottle connected with a cylinder of compressed oxygen is fitted with a suitable nozle to be inserted into the patient's nostril; and passes beneath the folded gauze from which the anesthetic is evaporated. Thus oxygen and ether may be given simultaneously but independently, and either may be increased, diminished, or suspended, without interfering with the other. When **nitrous oxid** is used as a general anesthetic, oxygen inhalations, as is well known, are a necessary part of the procedure (see page 338).

Respiratory Affections.—In cases in which air reaches the lungs in insufficient quantity, or in which the pulmonary surface is restricted, the employment of oxygen is *à priori* reasonable. In cases of **acute asphyxia** (strangulation, drowning, hanging) pure oxygen is rarely at hand. On the other hand, under certain conditions in which attacks of suffocation occur in paroxysms, such as **laryngismus stridulus** or other forms of **glottic spasm, laryngeal diphtheria** (Baillie, Bretonneau, Beigel), and **asthma** (Beddoes, Demarquay), the employment of oxygen has afforded distinct relief in a certain number of cases.

In cases in which **asphyxia develops slowly** oxygen can be efficacious only under certain definite conditions: the pulmonary surface of absorption must be sufficient and the absorbing power of the blood preserved. Oxygen acts under these circumstances in various ways. Whenever the pulmonary ventilation is insufficient,—in the presence of **emphysema,** for instance,—the indication exists to introduce into the lungs air as rich as possible in oxygen. Under other conditions (**pneumonia**) the oxygen not only supplies a concentrated respiratory pabulum, but also exerts a stimulating influence which is attended with slowing of the respiratory movements; the latter become more ample, the dyspnea is relieved, the blood-pressure rises, and an improvement in the general asthenia is brought about. **Croupous pneumonia** is certainly the acute disease in which oxygen is most often and most usefully employed. Next to pneumonia, is to be placed **bronchopneumonia** (Philip, Oppenheim). In such cases, however, to be efficacious it must be employed fearlessly, freely, and frequently, or even continuously; nor must its use be postponed until the patient is moribund —for, as S. Solis Cohen forcibly remarks, "it will not revive the dead." In mild cases, used early, inhalation for twenty minutes every two or three hours may suffice; in more severe cases every hour; and in some cases, as nearly without cessation as circumstances permit, for twelve or twenty-four hours together, or even over longer continuous periods. In pneumonia, according to S. S. Cohen, oxygen is not merely a res-

piratory medicament; doubtless it helps in some degree to overcome the toxemia, which is so important an element in the lethal issue.

Under other circumstances one may desire especially the **disinfectant** action of oxygen, as in cases of **fetid bronchitis, pulmonary gangrene** (Leyden and Jaffé), and **bronchiectasis** (Boucher).

In the presence of **pulmonary tuberculosis** inhalations of oxygen have been considered by some (Priestley, Jurine, Chaptal, Dumas, Monod) as useful, by others as useless (Fourcroy). They have been charged with favoring congestive attacks, and, in general, they are to be **avoided** in all cases in which the disease presents the character of acuteness and whenever hemoptysis is feared. J. Solis-Cohen permits the use of oxygen in pulmonary tuberculosis only as a measure of palliation in the late stages,—practically to mitigate the dyspnea of a prolonged death-agony. He believes it to be harmful in early cases by undue increase of morbid combustion.

Nervous Affections.—Oxygen has been prescribed also both as a sedative and a stimulant for the nervous system, as in cases of **epilepsy** (Ramskill), of **neurasthenia** (Demarquay), **neuralgia** (Hill, Hooper), of various forms of **paralysis** (Faucher, Lender), of **tabes** (Beddoes).

Diseases of the Kidneys.—Experience has not realized the hopes that were at one time based upon inhalations of oxygen as a means of treating **albuminuria.** Nevertheless J. Renaut recommends them in the presence of **uremic coma;** and Doreau, Huchard, and Bouchard in the **uremic dyspnea of eclampsia.** The indication is the same as in **diabetic coma;** the condition being one of **intoxication,** without reference to the underlying pathologic anatomy.

Gastric Disorders.—In the presence of certain varieties of dyspepsia, and in particular of **chlorotic dyspepsia,** Hayem has seen the appetite improve and the phenomena of vomiting subside. Pinard and Peter also have obtained good results in some cases of obstinate **vomiting of pregnancy.** On the other hand, Hayem has observed no effect from oxygen upon the vomiting of **uremia.**

OZONE

Ozone, the allotropic form of oxygen in which the molecule is said to contain three atoms (O_3 or O_2O), results in nature from the action of electric discharges and of certain forms of vegetation upon the atmosphere. It may be prepared by electric or chemical process. Therapeutically it has been used in most of the conditions in which oxygen has been commended. To it have been attributed all the therapeutic virtues of the latter, together with a much more energetic dis-

infectant action. Unfortunately it is not always easy to obtain the gas in a sufficient quantity and unmixed with toxic products, nitrous and nitric acids being generated in the oxidation of nitrogen which accompanies the preparation of ozone from atmospheric oxygen. Ozonized air is the preparation usually employed in medicine (Larat and Gautier). Ozone has been especially recommended by Lender, although at the time of his observations it was exceedingly difficult to obtain the gas in considerable amount

Technic

The apparatus constructed by Lender for the inhalation of ozone is no longer employed at the present time. The best means of preparing ozone in large quantities is to pass air or oxygen through a **narrow dielectric space** between two parallel conductors, as by means of a Siemens's induction tube or some similar device connected with a Holtz electric machine or a powerful Ruhmkorff coil—the silent discharge (effluvium) being more effective than the spark. Houzeau's apparatus consists of a glass tube about 0.1 millimeter in caliber, and from 40 to 45 centimeters in length, containing a stout platinum filament, and wrapped around with a spiral of some good conducting material, such as copper wire. One of the rheophores of the induction coil is connected with the platinum wire, the other with the copper spiral. The current of pure, dry oxygen gas is allowed to pass through the tube at the rate of one liter in an hour. The quantity of ozone produced is the greater the lower the temperature, about 50 per cent. of the oxygen being converted into ozone at —88° C. An effective machine based upon this principle, but much improved in detail, has been placed on the American market and has been described by W. J. Morton. The output of the machine is measured in milligrams of ozone in the minute and the dosage regulated accordingly. To remove irritating and deleterious nitrogen compounds the ozonized air is passed through a wash-bottle containing a solution of caustic alkali (sodium hydroxid or potassium hydroxid). When pure oxygen has been ozonized, this precaution is obviously needless. The apparatus employed by Labbé consists (1) of a generator of electricity furnishing a tension of 4 volts and flow of 2 ampères; (2) of a transformer of high tension represented by a Ruhmkorff coil with a spark of 2 centimeters; (3) of an effluvium tube in which the ozone is generated. This is virtually a condenser formed of two concentric glass tubes with large openings at their extremities. The discharge of this condenser takes place continuously without a spark in the form of a bluish-violet effluvium clearly per-

ceptible in the dark. The oxygen of the air contained in each tube is transformed into ozone, and becoming heated under the influence of the current, the air circulates sufficiently to render unnecessary the employment of bellows to propel it.

As ozone is always formed in greater or less quantity when oxygen is liberated or takes part in a reaction, especially if the evolution of heat be prevented, various **chemical processes** of production are available. Thus, several pieces of stick phosphorus may be placed in a large flask and half-covered with water; after some hours the flask will contain considerable ozone. A current of oxygen may be conducted over moistened phosphorus in a glass tube. Barium dioxid or potassium permanganate and oxalic acid may be added gradually, in small portions, to cold sulphuric acid.

Ozone may be allowed to diffuse through the air of an apartment, or (mixed with air or oxygen) may be collected over water in glass vessels. It cannot be collected in rubber, as it quickly destroys organic substances. It is soluble in pure water in the proportion of 8.81 per cent., the larger part, however, being converted by the water into oxygen without the formation of hydrogen dioxid. It is soluble in oils, some of them taking up as much as 25 volumes per cent. **Essential oils** and **terebinthinates** absorb ozone readily; they will also absorb oxygen from the air and convert it into ozone, becoming rich in ozone with long exposure. Doubtless some of the benefit attributed to the evaporation in sick-rooms of old turpentine, eucalyptus, and the like, depends upon the ozone given off.

Effects

Inhalations of **ozonized air** cause in animals an increase in the total amount of nitrogen, of urea, and of phosphoric acid eliminated (Butte and Peyron). Ozone has a marked effect upon the organism, and in excessive doses may cause **accidents** (Houzeau, Thenard, and Liebreich); a number of writers (Redfern, Richardson, Eulenberg) have noted inflammation of the air-passages developing rapidly and terminating fatally. Binz has confirmed this observation, and has noted, even with small doses and inhalations of brief duration, serious accidents preceded by a period of somnolence accompanied by depression of temperature. Binz observed in himself, at the end of a minute, a sensation analogous to sea-sickness. He speaks also of vomiting.

Inhaled in small quantity mixed with air ozone is absorbed and can be found in the blood (Binz); this explains its rapid action upon the brain-cells. After still smaller doses than those employed by Binz

one may rather observe symptoms of nervous excitation—a sense of intoxication, nausea, vertigo, and the like. In very small doses the inhalation of ozonized air increases the quantity of hemoglobin and hastens its reduction (Henocque). It is quite remarkable that this result may take place even after a single inhalation-séance.

The first **sensation** of which the patient in the ozonizing chamber is aware, is an imperious desire to breathe more deeply, the **frequency** of **respiration** falling more than half. In the first few minutes there are often some paroxysms of cough due to the irritation of the mucous membrane of the upper air-passages, after which the patient breathes easily, and without any unpleasant sensation. After repetition of the sittings for two or three days the cough (of pertussis or tuberculosis) diminishes and the expectoration becomes fluid, abundant, and less purulent. The appetite is increased, and sleep is improved. After from eight to fifteen days, there will be observed in slightly febrile patients a decline in the **temperature** and a cessation of night-sweats. The general state improves, the **weight** increases, and the tendency to hemoptysis gradually disappears.

Therapeutics

Ozone has, for a long time, been employed and advocated in the treatment of numerous diseases either as a substitute for oxygen, because of its greater activity, or as a disinfectant; but without inducing general resort to the agent. The more recent and more scientific observations of Labbé, of Henocque, of Butte and Peyron, and others, together with the improvements in methods of preparation, would, however, seem to have opened a new field for ozone-therapy, which, thanks to the apparatus devised by Labbé, is an absolutely innocuous measure that may be employed, even in the case of young infants, without causing any congestive phenomena. Thus, the action of ozone upon the hemoglobin of the blood mentioned by Henocque justifies its employment in the treatment of the various forms of **anemia** for which it had already been advised by Haller; and its influence upon oxidation (Butte and Peyron) permits a hope of an effect in cases of **diabetes,** of **gout,** of **obesity,** conditions for which Lender particularly recommended it. The therapeutic utilization of the **bactericidal action** of ozone, which its penetration into the blood (Binz) renders possible has, for a long time, been practised in cases of **infectious diseases.** Contemporaneous efforts have been directed especially to **whooping-cough** (Tripet) and to **pulmonary tuberculosis.** Many years ago Dewes successfully employed ozonized air in the former disease; but more recently

it has been enthusiastically advocated. Especially in the hands of Labbé, of Oudin, and of Sletoff, ozonized air has yielded excellent results in cases of **incipient tuberculosis** and in cases of **apyretic tuberculosis** with a tendency to fibrous evolution. Labbé states that he has patients who were cured in this way five and six years ago. Sletoff, who employed an apparatus almost identical with that of Labbé, has used ozone-therapy in 147 cases of tuberculosis, with favorable results. Ransome employed inhalations of ozonized oxygen (10 per cent.) from Waldenburg's gasometer with reported good influence upon the nutrition of phthisical patients. Before an authoritative recommendation can be made, however, as to the use of ozone in tuberculosis, there is need of a greater number of carefully controlled observations with reports after an interval of several years.

DIMINUTION OF OXYGEN IN RESPIRED AIR*

Beddoes looked upon pulmonary consumption as a process of morbid hyperoxygenation; basing the opinion on studies of the toxic effects of oxygen and of the morbid anatomy of phthisis. Further fortifying himself by citing the cessation of symptoms observed during pregnancy in consumptive mothers,—which he attributed to the abstraction of oxygen from the maternal blood by the fetus,—the increased wasting observed by Fourcroy in consumptives who had inhaled oxygen, and the opposite result attained by Percival with inhalations of carbon dioxid, he suggested that "it would be no less desirable to have a convenient method of reducing the oxygen than of increasing it by any proportion." Later he wrote to Erasmus Darwin that in view of the "essential difference between different cases of phthisis pulmonalis," and especially between the slowly developing and the florid forms, "which might require a very different method of treatment during the first stage," the reasoning in his book of observations was exclusively applicable to the latter variety.

Seeking to carry into practice this theory of the benefit of a 'lowered atmosphere' in pyretial diseases, and especially in florid consumption, Beddoes obtained the assistance of 'James Watt, engineer.' While the use of **nitrogen,** as the natural diluent of oxygen, was held to be a desideratum, the difficulty of preparing this gas unmixed with carbonic acid led to the selection of **hydrogen** as the 'lowering agent.'

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*Cited (as is much else in this chapter on Inhalation of Gases) from S. Solis Cohen's "Therapeutics of Tuberculosis," Phila., 1891.

The latter agent was afterward abandoned, for a time, in favor of what they called **'hydrocarbonate'** or **'heavy inflammable air,'** a somewhat variable and uncertain mixture, which, in the opinion of Henry Leffmann, probably contained methane or some similar hydrocarbon, hydrogen, carbon monoxid, and carbon dioxid, and, as at first prepared, hydrogen sulphid, from which last, however, Watt afterward purified it. Beddoes and his correspondents, Thornton, Carmichael, Pearson, and others administered this 'hydrocarbonate' diluted with common air in the proportion of about 1 in 20 (more or less, according to effect produced), giving from one quart to three quarts (liters) of the factitious air at a sitting. The patient inhaled the mixture for twenty or thirty seconds continuously; ceasing on feeling the premonitions of vertigo, and inhaling again when these symptoms passed off. The reports show that it reduced fever, checked cough, relieved pain and dyspnea, and promoted sleep. Its **hypnotic** power was so marked as to make Beddoes write: "An atmosphere with a diminished proportion of oxygen is a better soporific than any we at present possess." He narrates the case of a consumptive patient who was able to give up his opium and slept better, while his 'healthy servant,' the vapors being diffused through the room, 'did not know what was come to him, he slept so sound.' In some cases of pulmonary tuberculosis it apparently checked hemoptysis and night-sweats, and a number of cases are detailed in which complete recovery ensued. Some of these, of course, may, in the necessary absence of records of physical signs and of bacteriologic evidence, be thought instances of mistaken diagnosis.

NITROGEN

Nitrogen in the proportion of 79 volumes in the hundred enters into the composition of atmospheric air. The discoveries of Ramsay and of Lord Rayleigh have shown that the natural diluent of oxygen in the atmosphere is not pure nitrogen, but that a number of other elements enter into the mixture, of which the principal one is **argon.** The latter represents about one per cent. of the gases making up the sum-total formerly known as atmospheric nitrogen. It is more soluble than nitrogen, and by reason of this property it may possibly have quite an important action; but as yet nothing is known of this. Nitrogen and argon inhaled with air are absorbed by the blood in small quantities, 1.6 to 1.4 volumes in the hundred. According to Fernet, nitrogen should be taken up b[illegible] ored blood-corpuscles; but almost all the authorities [illegible] issolved in the plasma. Arterial blood has been found

by Magnus to be richer in nitrogen than venous blood. Although the nitrogen of the air plays an important rôle in nutrition in the vegetable world (Ville, Berthelot), this rôle appears to be quite limited in the higher animals.

The **therapeutic value** of nitrogen has been adequately recognized only within a few years; more especially by physicians at certain thermal stations. Nysten was the first to attribute to nitrogen certain medicinal properties which have since been utilized by Lecomte and Demarquay, Lemoine, Steinbruck, Treutler, and Mermagen (1880), especially in the treatment of tuberculosis, by the addition of from 3 to 7 per cent. of nitrogen to the inspired air. Whether nitrogen has a direct action or exerts its effect indirectly by diminishing the proportion of oxygen inhaled (see page 315) as was proposed especially for the treatment of febrile tuberculosis by Beddoes (1790) and revived by Valenzuela a century later, has not been determined. The principal writings upon the subject have been contributed by Treutler, Robden, Kempner, Hörling, Brugelmann, Zuntz, and the Spanish physicians at the stations of Panticosa, Urberoaga, Caldas-de-Oviedo (Aznus, Garcia Lopez).

Technic

The inhalation of nitrogen is employed practically at Lippspringe and at Paderborn (Inselbad).

At the stations where the springs contain large amounts of nitrogen in solution, the water is evaporated over fences of fagots, and in this way the nitrogen escapes. Treutler prepared the hyper-nitrogenized, or suboxygenated, air that he used, by causing cold air to circulate through iron filings mixed with iron sulphate. In order to obtain a distinct effect it is necessary to remove from the air more than 2 per cent. of oxygen, and, for safety, less than 7 per cent. should be abstracted. Many observers state that it is sufficient simply to rarefy the air in such a manner that to the action of insufficiently oxygenated air is added that of diminished pressure; but this introduces another factor, and is not to be commended except when the effect of negative pressure is in itself desirable (see Part I, chapters V and VII). If a sufficient demand were made upon the manufacturers of oxygen and hydrogen dioxid, doubtless nitrogen or nitrogenized air could be obtained in a compressed state in steel cylinders, and mixed with air or oxygen for inhalation in any desired proportion.

Valenzuela, believing the beneficial effects of **high alti**[illegible] **pulmonary tuberculosis** to be due less to the mechanical ef[illegible] rare atmosphere than to the absolute diminution of respire[illegible]

has devised an apparatus for the inhalation of **suboxygenated air.** To facilitate directions to patients he terms the process 'inhalation of nitrogen,' but physicians must understand that the therapeutic effect is not due to any positive quality of nitrogen, but to its negative quality —namely, the diminution of oxygen. His argument runs about thus:

In Spain the mortality from tuberculosis is about 20 per cent. of the total mortality in localities not more than 300 feet above sea-level, notwithstanding the ideal mildness of the climate of such regions as Malaga, Seville, and Valencia. At an elevation of about 1500 feet the proportionate mortality of tuberculosis falls to 10 or 12 per cent.; at about 3000 feet it reaches only 1 or 2 per cent.; and in regions more than 3900 feet above sea-level tuberculosis is entirely unknown in Spain, notwithstanding extreme variability, humidity, and rigor of climate in many such regions. Allowing for difference of pressure, air containing 17 per cent. of oxygen at sea-level is equivalent in oxygen-value to the atmosphere of 5500 feet elevation; 16 per cent. of oxygen is equivalent to about 7000 feet of elevation; and 12 per cent. of oxygen represents an altitude of about 15,000 feet. These may be termed, respectively, moderate, high, and extreme altitudes. The physiologic effects Valenzuela thus summarizes: *Moderate altitude* (17 per cent. O) stimulates respiratory movements, increases thoracic expansion, and augments excretion of carbon dioxid and of urea. *High altitude* (16 per cent. O) stimulates more markedly the respiratory movements, and diminishes nervous excitement, but does not modify nutrition. *Extreme altitude* (12 per cent. O) renders respiration extraordinarily active, disturbs the regularity of the circulatory rhythm, depresses markedly the nutritive movement (metabolism), diminishes temperature, sensibility, reflex excitability, and all other functions, and frequently produces epistaxis—a group of manifestations known as 'mountain-sickness.' These effects, Valenzuela asserts, are shown to be independent of diminution in pressure. (See also pages 179 and 190.)

To avoid elaborate apparatus, Valenzuela makes patients manufacture their own suboxygenated air by the very simple procedure of exhausting the oxygen by respiration. Carbon dioxid, water, and volatile principles, the products of respiration, are removed by fixation with caustic soda, condensation by cold, and solution in the condensed aqueous vapors respectively. From foreign bodies the air is purified by filtration. The **apparatus** consists of a porcelain vessel of twelve quarts' capacity, so constructed that the contained liquid exposes a lar— —'ace to contact with the air; a rubber bag to receive and retain

the expired air; and a tube of the same substance with a porcelain mouthpiece. A solution of caustic soda being introduced into the apparatus, the patient respires. The carbon dioxid is absorbed by the soda, the air of the apparatus commences to lose its oxygen, and, if not renewed, would become irrespirable, being converted into almost pure nitrogen in the course of about three minutes. To avoid this, and at the same time to reach and maintain a fixed proportion of nitrogen and oxygen, Valenzuela has devised a pair of valves, one of which permits a certain portion of the expired air to issue from the apparatus, while the other allows an equivalent volume of fresh air to enter it at the following inspiration. Without so intending, the author appears thus to have avoided the dangers of rebreathed oxygen. The apertures of the valves have been carefully calculated and the result verified by chemical analysis. There are three sets of valves, producing, respectively, the three proportions of oxygen already mentioned—12 per cent., 16 per cent., and 17 per cent. The apparatus is placed in the patient's chamber, so that he may use it at any hour of day or night for an appreciable time. Two hours daily, divided into three or four sittings, is estimated as the minimum time to be devoted to the use of the apparatus, and two months the least time of uninterrupted treatment. Much more than this is desirable.

Effects

The effects obtained by inhalation of nitrogen are of a sedative character. **Respiration** becomes easier and more regular, the **pulse** slower and softer; the **temperature** tends to decline; irritative or inflammatory phenomena on the part of the bronchial mucous membrane subside, and, as a result, expectoration diminishes. This last effect has been attributed to the attenuation of the stimulating action of the oxygen. Pain becomes less, sleep is improved, and nervous excitability disappears. According to Treutler, inhalation of nitrogen causes paleness and coldness of the skin, small, frequent pulse, and vertigo followed by headache, but never by syncope. Immediately after the inhalation there is a feeling of comfort and greater freedom in breathing, with some lassitude. It is a sedative by diminishing irritation through the exclusion of oxygen. Kohlschütter administered about 120 liters of a mixture containing 90 to 96 per cent. of nitrogen and the balance oxygen. It should be inhaled for half an hour daily for not less than four weeks. He observed, as did Treutler, quiet sleep, increased appetite, diminution of cough, of night-sweats, of fever, and of diarrhea, increased lung-capacity and augmented body-weight.

Therapeutics

Inhalations of nitrogen have been employed almost exclusively in **bronchitic affections** and in cases of **pulmonary tuberculosis.** In the latter malady Oertel found this agent of use in reducing local inflammation and suppuration and mitigating symptoms of irritation in general. Holzhauer employed a pneumatic chamber into which nitrogen was introduced in certain proportions, not for its own value, but to reduce the oxygen-proportion of the atmosphere. He observed mitigation of symptoms and increase of weight; at times resorption of infiltrates. Sieferman, as likewise Krüll and Mermagen, observed, from inhalation of a mixture of nitrogen (2 to 7 per cent.) with air, results similar to those of all the observers cited. Only in weak and anemic patients were unpleasant sensations produced, and not after the first two or three sittings. The last-mentioned observers report disappearance of apical dullness.

Valenzuela has collected statistics of more than 100 cases treated by himself and others, with 74.8 per cent. of favorable results, composed of cases of definite recovery and cases of improvement in the proportion of 2 to 3. In patients in whom the tuberculous process is of slow evolution, and who are early submitted to respiration of suboxygenated air—at a time, that is, when general nutrition is conserved and there is no fever, and they are considered as invalids only because of cough and hemoptysis; in whom, nevertheless, the diagnosis can be established by physical, spirometric, and microscopic evidence—recovery is the rule. The effects of this treatment upon pathologic conditions are said to be notable. In the first few days the cough disappears; dyspnea is no longer experienced upon exertion; intercostal neuralgia is relieved; color returns to the skin and mucous membranes; weight, chest expansion, and vital capacity augment. The patient becomes less susceptible to cold. Urinalysis shows more perfect oxidation of residual products, inasmuch as urea is increased and uric acid diminished. Even in advanced periods of the disease the treatment diminishes fever, checks sweating, and aids nutrition. Marked improvement, characterized as 'temporary recovery,' has been obtained. In acute tuberculosis the treatment is powerless. Valenzuela has attempted to combine with this method antiseptic inhalations, but his results are not definitive.

HYDROGEN

Hydrogen may be **prepared** extemporaneously by electrolysis of water or by the action of sulphuric acid and water upon zinc. It is

necessary to be sure of the purity of all the chemicals in order to avoid arsenical and other dangerous contaminations; and the gas should be well washed before use. It may also be obtained in cylinders under compression; and in such case, care as to its purity is likewise necessary—the more so, as theatrical lime-light purveyors and balloonists loosely apply the term hydrogen to coal-gas.

Effects and Therapeutic Uses.—The gas seems indifferent from a **physiologic** point of view, and in **therapy** has been employed only in mixture with atmospheric air, to diminish the proportion of oxygen in the latter. Among writers who have obtained good results we may mention Beddoes and Berzelius as cited by Demarquay. Inhalation of hydrogen employed in mixture with oxygen or air in varying proportions—1 to 1 (Beddoes), 4 to 1 (Berzelius)—should have sedative effects, and this should be one of the best means of restoring sleep in tuberculosis. Beddoes, indeed, attributed to it curative results in checking the hypercombustion or excessive oxidation that he conceived to be a fundamental morbid process in certain forms of consumption. (See page 315.) The method is worthy of more extended observation in suitable cases.

CARBON DIOXID

Carbon dioxid (CO_2) is contained free in atmospheric air in the proportion of from two-tenths to three-tenths per mille. It likewise exists in a free state in the lungs, resulting in large part from the chemical processes of life. It is not merely a waste product of nutrition, but exciting physiologically the breathing centers, it is in some respects the functional regulator of the respiration.

Technic

The crudest procedure consists in breathing carbon dioxid as it escapes from an ordinary **siphon-bottle** containing Selters or other highly charged carbonated water, from which one removes the siphon-tube, or which one inverts. The same purpose may be fulfilled by means of bulbs containing liquefied carbon dioxid, such as are sold in the form of the so-called 'sparklets'; but these procedures are not to be recommended, because the addition of carbon dioxid to the air of respiration in this manner diminishes the proportion of oxygen undesirably. I prefer the following apparatus: A glass receptacle is provided with two orifices so arranged that into one may be introduced a bulb of liquid carbon dioxid and into the other a globule charged

with liquid oxygen. The gases mingle in the vessel, whence a tube leads to the mouth, where the gaseous mixture enters the air-passages with the inspired air.

The '**nasal sparklet**' is certainly less practical and less conformable to physiologic exigencies. It has, however, in my hands yielded good results. Into a rubber bag is introduced a bulb containing liquefied carbon dioxid, which upon penetration of the envelope resumes the gaseous state and fills the bag; from which it may then be allowed to enter the nasal passages. By varying the opening of the stopcock attached to the bag, the pressure of the gas can be increased or diminished at will. In order to empty the apparatus completely, the rubber bag may be compressed gently.

Certain **hydromineral stations** are especially equipped for the inhalation of carbon dioxid. In the year 1834 Gouin made known the various applications of carbon dioxid at the waters of St. Alban. Since that time similar installations have been made in Austria at Eger-Franzensbad; in Bohemia at Marienbad and at Carlsbad; in France at Challes, Royat, Vichy, Saint Nectaire and elsewhere; in Germany at Nauheim and at Canstatt. The gas escaping from fissures in the earth or from springs is collected and utilized in the pure state or mixed with atmospheric air, dry, or in combination with steam.

Herpin has constructed various forms of apparatus for inhalation.

Pure carbon dioxid, liquefied, can be obtained in cylinders from which it can be drawn as gas into a **gasometer** or **gas-bag,** and mixed with air or oxygen in definite proportions for inhalation. The gas can be **prepared extemporaneously** by the action of purified sulphuric, acetic, or other available acid, or of a solution of potassium bitartrate or sodium bisulphate, upon sodium bicarbonate, chalk, or marble-dust. A convenient method is to place the acid powder and the sodium bicarbonate together in a suitable flask, and to allow water to drip upon the mixture through a glass funnel provided with a glass stopcock to regulate the flow (Fig. 59). The carbonic acid gas escaping through an outlet tube is collected in a rubber bag into which has previously been introduced a measured quantity of air or oxygen; thus, 9 gallons of oxygen in a 10-gallon bag, if one desires a mixture containing in ten volumes, one volume of carbon dioxid.

In certain stations at mineral springs respiration takes place in **cabinets,** in which the carbon dioxid is allowed to reach the upper portion of the enclosure in any desired proportion. The sittings are brief, from ten to twenty minutes or more, in accordance with the tolerance and habituation of the patient.

Some such method of exact mixture should replace the primitive procedures in which the gas emanating from a spring or previously received into a gasometer is respired undiluted through the mouth, the nose respiring ordinary air. The **proportion of carbon dioxid** admixed with air should not exceed 8 per cent., or with oxygen, 10 per cent.

Effects

The perturbations resulting from the inhalation of carbon dioxid have been studied with care by Demarquay, Nothnagel, Friedländer and Herter, Gerhardt, and others. A proportion of 1 per cent. in the inspired air gives rise to an appreciable disturbance, while if the proportion is greater, anxiety, headache, vertigo, ringing in the ears, and a kind of intoxication follow. The **pulse** becomes slow, general **convulsions** supervene, and, finally, loss of consciousness and **death**

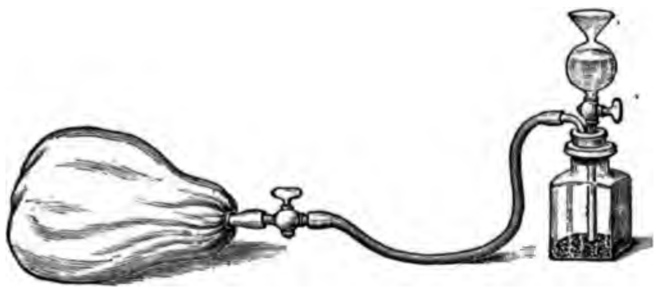

FIG. 59.—CARBON DIOXID GENERATOR AND RECEIVER.

by respiratory paralysis, as with the anesthetics; and it will be seen that carbon dioxid is, in fact, a true anesthetic agent. There is excitation of the respiratory center, as the result of which **dyspnea** occurs; and of the vasomotor center, as a result of which there is increased **blood-pressure.** If the proportion of carbon dioxid be increased, the phenomena of excitement will be followed by **paralytic phenomena** of the same centers.

Is it the augmentation of the carbon dioxid in the blood or the **diminution of the oxygen** that causes these phenomena? According to Nothnagel and Rossbach, it is the increase in the carbon dioxid that is responsible. An observation of Gréhant tends to demonstrate the contrary, and I am inclined to agree with him, because it permits us to understand the useful action of medicinal inhalations of this gas. If in atmospheric air one substitutes a proportion even so high as 5 per cent. of carbon dioxid, not for the oxygen, but exclusively for the

nitrogen, one may sustain life in a rabbit for several hours. With a proportion of only 30 per cent. of carbon dioxid mixed simply with atmospheric air, death follows at the end of this time. The mixture prepared according to the direction of Gréhant induces anesthesia of the cornea in the course of two minutes, and this may persist for two hours. There is also a considerable diminution in the frequency of respiration. Demarquay found that he could support for a short time inhalation of a mixture of one-fourth carbonic acid to three-fourths oxygen, while some of his pupils could bear even one in three. For therapeutic use, however, it should not be greater than two parts of carbonic acid to eighteen of oxygen. Twenty liters of such a mixture caused a sensation of heat in the chest, quickened breathing with relatively prolonged expiration, and transient vertigo, preceded by slight cephalalgia. There was no effect on the pulse. The greater proportions of carbonic acid, however, produced more severe vertigo, accelerated, feeble pulse, redness of the face, with some prominence of the eyeballs, and anxious and panting respiration. According to B. W. Richardson, carbonic acid causes coagulation of mucous secretions. Some ten years ago Bergeon's rectal injections of carbonic acid and sulphuretted hydrogen led to a temporary and limited revival of other methods of administering carbonic acid, to which agent the good results were by some attributed. Were the common notion of the highly poisonous effects of carbonic acid, or the attribution to that gas of the deleterious effects of a vitiated atmosphere, correct, there would be an obvious objection to its employment by inhalation. But the experiments of the observers quoted, the experience of J. Solis-Cohen and James Collins, together with the observations already cited of B. W. Richardson upon 'rebreathed oxygen,' and of Brown-Séquard and D'Arsonval, tending to show that some product of katabolism other than carbonic acid is the most powerful toxic agent in unventilated places, are sufficient to set this objection aside. In medicinal dilution and usage carbon dioxid is not poisonous. Its anesthetic properties and its power to promote cicatrization are now frequently utilized in the treatment of burns, gangrene, and the like; and there is no reason why they should not be made to serve an equally good purpose in the air-passages.

Therapeutics

As with most other gases, **tuberculosis** is the disease in which inhalations of carbon dioxid also have been most often recommended (Percival, Beddoes, Gouin, Villemin, Durand-Fardel, Gubler). It lessens especially the dyspnea and the cough, and this sedative action may persist

for several hours and even for several days. Weil, who has recently written on the subject, has the patient take two sittings daily of from two to five minutes' duration. He has observed relief from the dyspnea in cases of **heart disease** and of **chronic nephritis,** and a reduction in the frequency and the duration of the paroxysms in cases of **whooping-cough.** Carbon dioxid has been recommended also for the relief of the pain, sometimes intolerable, in cases of **laryngeal tuberculosis.** It has, further, been praised in the treatment of **asthma,** of **catarrhal bronchitis,** of **nervous cough,** of **epistaxis,** of **ozena,** of **hay-fever,** and of various **nasal affections.**

Inhalations of carbon dioxid in phthisis, as mentioned, were employed by Percival, who says that, although he had not been so fortunate as Dr. Withering in effecting a cure, "the hectic fever has been considerably abated and the matter expectorated has become less offensive and better digested." Beddoes and some of his correspondents likewise used this agent with occasional good effect, and the former attributed part of the benefits of residence in and near cow-stables to the carbonic acid exhaled by the cows and given off by the fermenting dung. While he preferred hydrogen as an agent to reduce the proportion of oxygen in the atmosphere, he attributed to carbonic acid a special power in promoting the healing of ulcerated surfaces; fortifying the opinion by records of experiments on blistered surfaces and cutaneous ulcerations, as well as by the citation of pulmonary cases.

Greater attention should be paid to this agent by those who do not seek for impossible panaceas, and can use it, therefore, for definite ends, palliative or curative as may be, and be satisfied with attainment of the ends aimed at. It is well to relieve even when we cannot cure.

CHLORIN

The employment of chlorin by inhalation, very much in favor about 1830 in the treatment of **tuberculosis,** is almost completely abandoned at the present day, partly on account of the lack of positive proof of its good effects, and partly on account of its dangers (Louis, Skoda). This is because it possesses irritating and caustic properties of an extremely pronounced character, particularly upon the mucous membranes. The employment of chlorin inhalations in the treatment of **poisoning** by **hydrogen sulphid** and by **hydrocyanic acid** has also fallen into disuse.

It is, however, well to recall that the inhalation of chlorin vapor was at one time in vogue. Having noted that tuberculous patients

working in bleaching establishments in which were employed solutions of hypochlorites, giving off the vapors of chlorin, experienced some relief of symptoms, and that their lesions had a tendency to undergo cure, Gannal (1819) studied systematically the effect of inhalations of chlorin in cases of tuberculosis, and obtained encouraging results (1828). The favor with which this new medication was received was increased by the publication of Cottereau (1831), who reported 30 cases in proof of its efficiency. In one case cicatrization of the lesions was found two years after treatment, death having supervened at this time as the result of some acute intercurrent pulmonary disease. Other reports were less favorable, and Louis, after observations upon 70 patients was compelled to deny any curative effect of inhalations of chlorin in the treatment of tuberculosis. Toulmouche considers them as having no other effect than to facilitate expectoration and to increase the appetite. Stokes, Morton, and Little pointed out the **dangers** of chlorin according to the technic then in vogue and advised against its employment. Like many other useful agents, it has been overlauded and overneglected. Recently Shurly and Gibbs (1891) have prominently recalled attention to its merits.

Technic

The undiluted gas is irrespirable, and unless due caution be used its irritating and toxic properties will outweigh any good due to its disinfecting and stimulating powers. It may be evolved in proper dilution for inhalation by mixing one or two drams of chlorin-water with a couple of ounces of hot water, and placing the vessel in a hot bath or over a flame; or it may be diffused through the air of an apartment by allowing a saturated solution of chlorinated lime to drip upon diluted sulphuric acid in Corrigan's apparatus or some more modern generator. Shurly makes use of one of two methods: when there is laryngeal ulceration, he diffuses a spray of (saturated) sodium chlorid solution through a small room, in which chlorin gas is afterward evolved in the proportion of from 1 : 20,000 to 1 : 4000 of the air-content.* The diffusion of salt and gas being complete, the patient enters and remains at first ten minutes, afterward half an hour or longer, in the medicated atmosphere; the spray of sodium chlorid being continued.

* "In a small room or compartment, of about 550 cubic feet, place from a half dram to six drams of chlorinated lime, spread out in a saucer or shallow glass, and to this add slowly from one to three drams of dilute hydrochloric acid, stirring with a wooden spoon or spatula. One-half dram is the commencing amount, and more should be added each day until about three or four drams are used."

The patient is directed to keep the mouth closed and breathe through the nose. When there is no ulceration, sodium chlorid solution and recent chlorin water are mixed in a suitable inhaler.

S. Solis Cohen has found it perfectly feasible to use, even in cases of ulceration, chlorinated water and sodium chlorid solution in the Oliver nebulizer (Fig. 60). The relative quantities are found by experiment for each patient; when the chlorin water is very recent, one part to two of sodium chlorid solution—or with less recent chlorin water, equal parts—will represent the average proportion. From half an ounce to two ounces of the mixed solutions may be vaporized at a sitting, and there may be from one to three or more sittings a day. Chloroform may be used to mitigate the sharpness of chlorin vapors, and has a certain utility of its own as an antiseptic, apart from its anesthetic quality. Other inhalers, constructed on the principle of Oliver's—that, namely, of producing a spray with Bergson's or Richardson's tubes, and breaking this up into a veritable nebula by impact against the wall of the containing vessel or other convenient obstacle—may likewise be employed. According to Cohen, the inhalation of chlorin in this way helps to control suppuration in phthisical cavities, and in some cases apparently causes the disappearance of bacilli from the sputum. Usually it is better for the patient to inhale soon after a thorough expectoration, and not too near meal-times, as not infrequently there is a striking effect upon the stomach, as shown by nausea and vomiting (Shurly). In some cases the inhalations have to be abandoned on this account. It is in cases of **chronic bronchitis** (Louis, Thomson), particularly in cases of **fetid bronchitis** (Stokes), that chlorin would yield the best results. The remedy has been advised also in the treatment of **laryngeal diphtheria** (Bretonneau) and in certain cases of **aphonia** (Pancoast), in which it acts especially, if not exclusively, as a local stimulant.

FIG. 60.—OLIVER'S NEBULIZER.

ILLUMINATING GAS (CARBURETTED HYDROGEN)

It was in 1864 at Amsterdam, and then at Calais, that the inhalation of illuminating gas was applied on a large scale in the treatment of

whooping-cough. The paper of Commerge summarizes the action of the gas in 152 cases of whooping-cough treated at St. Mandé, near Paris. The results were excellent in all periods of the disease. It was necessary to give a dozen séances of two hours in order to effect recovery. The **technic** is simple. It consists in having the patients spend their time in the depurating chamber of illuminating gas-works.

Since then observations have multiplied and the results appear less good, so that the method has fallen into complete disfavor. Nevertheless it is quite certain that this treatment diminishes the intensity of the paroxysms and reduces their number. I have observed this fact on many occasions. But is it the illuminating gas that has this effect? Is it not rather the ammonia and the vapors of tar (Bartholles); is it not rather the benzene (Lockner)?

HYDROGEN SULPHID

Hydrogen sulphid (H_2S), or sulphuretted hydrogen, is a powerful **toxic agent.** It may readily be generated extemporaneously, by simply placing in hot water a few lumps of sodium or potassium sulphuret, but practically it is employed at present exclusively in the form of natural sulphurous mineral waters, which permit the escape of a considerable amount of gas. The discussion of this subject will be taken up in a special section. At this point the editor would recall attention to the method of obtaining within the patient a sulphuretted atmosphere, which we owe to the ingenuity of Bergeon,* of Lyons. Taking the suggestion from the observation of Claude Bernard, that when gases, otherwise poisonous, are introduced into the large intestine they will be absorbed into the blood, and eliminated by way of the lungs without reaching the arterial circuit, Bergeon advocated and practised the administration **by rectum,** for local effect upon the entire respiratory tract, of a mixture of hydrogen sulphid, and carbon dioxid free from air. Unfortunately, the notoriety given this treatment by American newspapers, the methods of some who practised it, its exploitation by instrument-makers,—some of whom furnished very defective apparatus,—and its irrational and indiscreet handling by persons incapable of judgment, have brought it into ill repute. The editor desires, however, to reaffirm here what he has elsewhere † said

* "Comptes Rendus de l'Acad. des Sci.," t. CIII, Paris, 1886, p. 176 et p. 659; "Bull. de la Soc. anat. de Paris," 4 S., t. XI, 1886, p. 609.

† "Recent Advances in the Treatment of Pulmonary Consumption," "Transactions of the Medical Society of the State of Pennsylvania," 1887.

concerning its use in cases of **pulmonary tuberculosis**—namely, that as an adjunct to other methods of treatment it is distinctly helpful in certain conditions; not all the observers * who found it of benefit were inexperienced incapables or unbalanced enthusiasts.

The measure is probably, as asserted, without influence on tubercle bacilli, but it does most certainly help to control suppuration and putrefaction in phthisical cavities, to stimulate healthy secretion of the respiratory membranes, and to heal laryngeal ulcerations. Symptomatically, it reduces cough, checks diarrhea, lowers temperature—often amazingly—and promotes sleep. It also increases appetite, and, if sufficient and suitable food be given, the treatment is followed by gain in weight. Before softening, however, it is unnecessary; and in cases far advanced it is unavailing as a curative measure, though useful in palliation. In what may be generalizingly called 'second-stage' cases it helps recovery, however, in two ways—through the cicatrizing properties of carbonic acid, pointed out by Beddoes and confirmed by a hundred years' experience; and through the action of the sulphur gas in combating the septic decompositions that are superadded to the tuberculous degenerations and phthisical excavations.

In order to obtain pure carbon dioxid, Bergeon deemed it necessary to evolve the gas by chemical process at or about the time of administration. Having been collected in a rubber balloon (see Fig. 59, page 323), it is then passed by means of rubber tubes and hand-bulb through a flask of warmed natural or artificial sulphur-water, and, taking up the hydrogen sulphid on its way, the two are slowly introduced into the rectum. From two to six quarts of carbon dioxid are used, and a sulphur-water of about the strength of that of Eaux Bonnes.† Care must be taken that all air is ejected from the apparatus before the delivery-tube is placed in the rectum.

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* Burney Yeo, C. Henry Bennett, Sinclair Coghill, J. Solis-Cohen, De Renzi, Cornil, Bruen, and many others. See reports, good, bad, and otherwise, collected in Wesener's admirable epitome of "Die Antiparisitäire Behandlung der Lungenschwindsucht," "Centralbl. f. Bacteriologie und Parasitenkunde," No. 16, Bd. IV, 1888.

† The Mt. Clement is the best American water. A good formula for artificial sulphur-water for this purpose is that suggested by Bardet and modified by Yeo: Add to 8 fluidounces of water, 3 fluidrams each of the following solutions:

No. 1.
Sodium sulphid, *c. p.*, ½ ounce;
Distilled water, 6 fluidounces.—Mix.

No. 2.
Tartaric acid, 10 drams;
Salicylic acid, ½ dram;
Distilled water, 6 fluidounces.—Mix.

From ten to twenty minutes are consumed in each injection, and two injections * are made daily.

Effects

Inhaled in small amount hydrogen sulphid gives rise to headache and vertigo, with pallor of the face. The **pulse** becomes accelerated and feeble, eructations occur, with nausea, abdominal pain, and diarrhea. The **secretion** of sweat and the bronchial secretion are modified. Increase in the process of disintegration of nitrogenous substances has not been demonstrated. The proportion of sulphuretted hydrogen admixed with the air may be quite considerable without causing injury.

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* Morel ("Nouveau traitement . . . . par les injections rectales gazeuses," etc., Paris, 1886) gives the following directions:

"This operation demands a certain amount of experience and several precautions. The patient should be as much disrobed as possible, or at least not wear any dress, corset, or belt that would compress the abdomen, which necessarily swells a little on the entrance of the gas into the large intestine. It is best that he should lie on his back.

"When an injection is made for the first time, it is well to note with the hand the resistance made to the entrance of the gas into the intestine—to go slowly or to stop a little if the resistance be very great, which announces that the intestine is filled, and to wait until the absorption takes place, and then resume again, and so on.

"It is also necessary to note the sensations of the patient—to stop quickly if he is attacked with colic or has an inclination to stool. In some cases this is so imperative that it has to be obeyed, and in this case, when the intestine has been emptied, the injection is resumed. It is not necessary to take evacuants before the injection. In cases where the extent of the pulmonary lesions is very great, and in consequence the gaseous elimination is made but slowly, it is necessary to proceed very slowly on account of the sensation of fullness in the chest and abdomen. It is necessary to take fifteen to twenty minutes to administer the first injection.

"The first operation at least should be made by the physician himself, in order that he may take note of the susceptibility of the patient to the action of the gas, the rapidity with which the absorption and elimination take place, and the manner in which the intestine tolerates the gaseous mixture. It should not be confided to the patient or his attendants until the physician is able to give them precise instructions. He should not give over these injections into the hands of the patient, any more than he would the administration of hypodermatic injections of morphin or other substances of the same kind. In one case as in the other serious accidents might result if account were not taken from time to time of the conditions that affect and result from the injections—conditions that vary necessarily in one patient and another, and for which general rules cannot be given.

"The rectal injections should be made three or four hours after meals or immediately before them. If taken too soon after meals, they are likely to produce vomiting, if nothing worse. For the first injection it is well to use only part of the volume of carbonic acid in the gas-bag, say about three liters. After three or four operations an injection of six liters is readily tolerated morning and evening."

The mineral-water bottle should be kept in a hot-water bath in order to maintain the gases at a temperature of about 100° F.

It is **eliminated** in part through the urine (Diakonow), but if it is used only in small quantities, the larger portion is fixed in the tissues (Peyron).

Therapeutics

The **indications** for the inhalation of hydrogen sulphid are numerous, and include **chronic catarrhal laryngitis, chronic bronchitis, with or without bronchiectasis, torpid fibroid tuberculosis**; while a congestive or hemorrhagic tendency constitutes a formal **counterindication.**

SULPHUROUS ANHYDRID (SULPHUR DIOXID)

Sulphurous anhydrid (SO_2) is produced by the combustion of sulphur in free air. It has an undeniable **antiseptic action,** and for a long time it has been employed for the disinfection of contaminated apartments (Sternberg, Thoinot, etc.; see also volume v of this series). Inhalations of this gas have been recommended since antiquity in the treatment of certain **bronchopulmonary** affections, and in particular of **tuberculosis.** Baumes said that those engaged in sulphuric-acid manufacture were protected against phthisis, or, if affected, recovered; and Julius Kircher, a manufacturing chemist in Brooklyn, states that a large quantity of sulphur is vaporized daily in his establishment, and during forty-four years he has had no laborer affected with consumption, while many entering his employment in the early stage of the disease have recovered and become strong and stout. Quite recently inhalations of sulphur dioxid (commonly called sulphurous acid) have again been recommended by Sallard and by Dujardin-Beaumetz.

Technic

Galen sent patients with phthisis and with laryngeal and tracheal ulcerations to certain regions in the vicinity of Mount Vesuvius and Mount Ætna, where they might breathe the natural sulphurous emanations. One need not, however, insist upon this historic method; it suffices to diffuse through the air of an apartment sulphurous anhydrid, mingled, if possible, with carbon dioxid. For this purpose 10 parts of flowers of sulphur, slightly moistened with alcohol, may be burned with 1 part of charcoal in an open vessel. Dewar sprinkled sulphur in successive small quantities on red-hot cinders contained in a kitchen-shovel placed upon a stool in the middle of the room. Dujardin-Beaumetz burned in a close room 150 grains of sulphur for every cubic yard of space (250 grams in a room of 25 cubic meters' capacity), and twelve hours later had the patient enter the room and remain for

four hours. There have been manufactured candles impregnated with sulphur, which will burn for a period of from five to ten minutes, or longer as desired, consuming about ten grams of sulphur in the hour (Deschiens). Kircher recommended as a practical expedient that patients should remain in a room where hourly one to two drams of sulphur are vaporized on a warm stove. Burning carbon-bisulphid with a wick in a lamp is one of the best methods, as it likewise diffuses carbon dioxid; and whether this or other expedient be chosen, some of the irritating effects may be mitigated by burning at the same time opium and gum benzoin (Auriol). If necessary, the windows may be opened from time to time. Bartholow has advised the use of the 'Pictet liquid,' which consists of a mixture of sulphur dioxid and carbon dioxid liquefied under pressure, and obtainable in siphons like those in which mineral waters are supplied. The windows of a small room being closed, the room vacated, and the door shut, a tube connected with the delivery-nozle of the siphon is passed through the keyhole, and, the released liquid quickly resuming the gaseous state, a certain quantity—arrived at by experiment as to the tolerance of the individual—is allowed to diffuse through the atmosphere of the room. The patient then enters and remains as long as possible, —from a few minutes to a few hours,—the time varying with the quantity of gas diffused and the individual tolerance. Another method is to mingle sulphur dioxid with carbon dioxid and air in a suitable container, from which the patient may inhale; but this is a difficult and annoying process.

Effects and Uses

Sulphur dioxid is classed among disinfectants, and its virtues are usually attributed to its deleterious influence on low forms of life and its power to destroy certain organic matters by combining with oxygen. Inhaled undiluted, it produces spasm of the larynx, and, if in sufficient quantity, violent inflammation of the air-passages. In respirable proportion it stimulates healthy secretion and restrains unhealthy secretion and pathologic exudates. It has been stated that the more severe the pulmonary and laryngeal lesions, the greater is the tolerance of patients. Some persons cannot endure even a mild sulphurous atmosphere, save for a very short time, owing to severe irritation of the conjunctiva, although the throat may not be affected. In cases of **pulmonary tuberculosis** Dujardin-Beaumetz observed lessening of the expectoration, the sputum becoming less purulent; emaciation also was checked; but the lesions persisted and their evolution continued.

Moreover, the favorable results were inconstant. Weisberger has recommended inhalations of sulphurous anhydrid in the treatment of **whooping-cough.** In solution it has been used as a disinfectant spray in **diphtheria, scarlatinal angina,** and other affections of the throat (see page 429).

HYDROFLUORIC ACID

Hydrofluoric acid (HFl) is a gas, but the hydrofluoric acid of commerce is a solution of this gas in water, in the proportion of from 30 to 40 per cent. Some fifteen years ago a great furore was raised with regard to hydrofluoric acid as a remedy in the treatment of **pulmonary tuberculosis,** for which, indeed, it had been employed by Bastien in 1862. It was believed that workmen engaged in etching upon glass with this agent were rarely attacked by tuberculosis, while tuberculous persons who entered this occupation were benefited. Among others, Chevy, Seiler, Garcia, Moreau and Cochez, Trudeau, Goetz, Raimondi, recommended the new method. Others opposed it. A commission of which Herard was the head reported favorably to the Académie de Médecine (Paris); but many continued to be skeptical. The question was at last definitely settled in the negative by the thesis of my pupil Brunet.

Effects

The **antiseptic** power of hydrofluoric acid has been demonstrated by Chevy, who found that solutions of 1 : 1000 or 1 : 2000 arrested the putrefaction of milk, of bouillon, of meat, and of urine. But is it capable of destroying Bacillus tuberculosis or of attenuating its virulence? This is the opinion of Chevy, of Herard, of Trudeau; but the careful experiments of Jaccoud and Bourcy, and of Grancher and Chautard, raise a doubt upon this point. It is true that the vapors of pure hydrofluoric acid will sterilize tuberculous sputum, but the vapors emitted by a mixture of equal parts of water and hydrofluoric acid, even at the end of forty-five minutes, fail to exert any bactericidal action (Jaccoud and Bourcy). Inoculation experiments indeed showed that cultures of tubercle bacilli exposed to the action of the vapor of dilute hydrofluoric acid (from 20 to 60 per cent.) had suffered considerable diminution in virulence; but, on the other hand, inhalations of hydrofluoric acid failed to produce any effect upon the inoculated animals (Grancher and Chautard).

The **administration** of air charged with hydrofluoric acid in the proportion of 1 part to 1500 is well tolerated by human beings; the patients complain only of slight irritation on the surface of the nasal

and ocular membrane, of a desire to cough, and sometimes, during the first sittings, of a slight degree of headache.

Technic.—The patients breathe either in a chamber that is almost entirely closed, or in a special cabinet. The hydrofluoric acid solution may be placed within the apartment in a lead receptacle, and heated (Dujardin-Beaumetz); or in a leaden or rubber vessel outside, and the air allowed to pass through it before entering the cabinet (Seiler and Garcin). The gas being heavier than air, the fluorized current should enter the upper portion of the cabinet (Lepine). The **dose** of hydrofluoric acid is about 30 liters (quarts) of air saturated with the acid for each cubic meter of space. The **duration** of the sitting varies from fifteen to thirty minutes.

Therapeutics

Hydrofluoric acid has been recommended in the treatment of **diphtheria** (Bergeron), but it has been especially praised in the treatment of **tuberculosis.** Inhalations of hydrofluoric acid were administered by Brunet to more than 100 patients in all stages of tuberculosis. Observations with regard to the weight, the progress of the lesions, the expectoration, the urine, etc., were recorded. It is certain that during the first days amelioration may be observed; the cough becomes less distressing, the expectoration more fluid, the dyspnea diminishes, strength returns, weight increases; but the gain is only transient. The most conspicuous feature is the improvement in the gastric condition. This is shown in the disappearance of vomiting, and especially in the return of appetite. But if the observation be continued, it will be found without exception at the end of several months that neither local nor general improvement has been maintained.

Hydrofluoric acid is badly borne in cases of tuberculosis complicated by **emphysema,** and by patients predisposed to **hemoptysis.**

FORMALDEHYDE

Like hydrofluoric acid, formaldehyde (CH_2O) is a gas that is found in commerce in the form of a 40 per cent. solution (formol or formalin). It is an extremely powerful antiseptic even in great dilution, having a destructive action upon the bacilli of typhoid fever, of diphtheria, upon the microbe of putrefaction (Aronson, Berlioz et Trillat), and upon the anthrax bacillus. The dry vapor of formaldehyde destroys the bacilli of tuberculosis in the sputum dried or triturated with sand, sterilized and dried, and even in moist and recent sputum (Bosc). For-

maldehyde is used especially for purposes of **disinfection.** (See volume v.) It has been employed also in the treatment of **tuberculosis.**

Technic.—In volume v the various methods of evolving formaldehyde gas extemporaneously are described. In medicinal inhalations the lamp of Tollens or of Trillat is often employed. Many forms of apparatus have been constructed for the generation of formaldehyde by oxidation of the vapors of methylic alcohol in the presence of a close-meshed sheet of platinum brought to incandescence. Formalin pastils may be used in Schering's lamp with a few crystals of menthol. **Moisture** must be present in the air of the apartment for due effect. A 25 per cent. solution of the commercial formalin may be placed in a Woulff bottle inhaler (see page 349) with a few drops of eucalyptol, gaultheria, and chloroform.

FIG. 61.—AMMONIUM CHLORID INHALER TO BE ADAPTED FOR FORMALIN AND CHLOROFORM.

Hamaide sends a current of carbon dioxid gas diluted with air (1 : 10) through a flask containing a solution of formalin (2 to 10 per cent.) in warm water—to which a few drops of pine oil or other terebinthinate or balsamic essence may be added—and has the patient inhale the vapors thus carried over. W. G. Shallcross covers a sheet of wire gauze with cheese-cloth, rolls it into a cylindrical spiral which he places within a large inhaling flask, and pours upon the absorbent covering a small quantity of solution of formalin (5 to 25 per cent.) in rectified spirit. To this also, chloroform, menthol, cloves, eucalyptol, guaiacol, gaultheria, and the like, may be added. Shallcross uses an inhaling mask of soft rubber made by scissoring an ordinary atomizer bulb. Acting upon a suggestion made by Mr. J. W. England, of Philadelphia, the editor has modified Shallcross's inhaler by substituting a sheet of phosphor-bronze-gauze for the iron-wire, and utilizing as the containing vessel a common form of ammonium chlorid inhaler (Fig. 61). In the small vial intended for hydrochloric acid is placed a solution of chloroform (1.0, say 15 minims) and oil of peppermint (0.5, say 8 minims) in alcohol (2.5, say 40 minims). The air being drawn through this sedative solution before it becomes charged with the formaldehyde the irritating properties of the latter are mitigated. Glycerin is often added to inhaling mixtures containing formalin,

but some authors caution against its use, stating that chemical reaction gives rise to acrid and poisonous compounds.

Therapeutics

The vapors of formaldehyde when mixed with carbon dioxid are readily tolerated by **tuberculous patients** (Cornil). The sittings vary from fifteen to twenty minutes in duration. The results obtained at the Sanatorium of Villepinte (Lefevre) are most encouraging. The sputum was observed rapidly to lose its purulent character. It is not correct to charge formaldehyde with favoring the occurrence of hemoptysis. According to Gouel, who has obtained the best results from formaldehyde, the best means of establishing tolerance is to add either menthol or thymol, themselves antiseptic and anesthetic substances. S. Solis Cohen advises, frequent inhalation of formalin and chloroform vapors by patients presenting **phthisical cavities, pulmonary gangrene, fetid bronchitis,** and other septic conditions of the air-passages. He employs Schering's lamp with paraform pastils, menthol, and eucalyptol, to charge continuously and mildly the atmosphere of the room in which such patients or children with **whooping-cough** sit, play, or sleep, and also at times resorts to the same expedient in the sick-room or an adjoining chamber, in cases of **scarlet fever** and **diphtheria.** In diphtheria, Donaldson burns in the closet adjoining the patient's chamber, candles or tablets that disengage formaldehyde gas, leaving the door open long enough to charge the air of the sick-room appreciably but not disagreeably; or in preference charges a room and moves the patient into it for the day, meanwhile charging another room into which the patient is moved back at night—and continuing thus to alternate. He reports a beneficial influence in a limited number of cases.

AMMONIA

Ammonia (NH_3) is rarely employed by inhalation. Its irritant action upon the pituitary membrane (trigeminal nerve) may be utilized to awaken respiratory movements in cases of **syncope,** in cases of **poisoning by narcotics,** and in cases of profound **alcoholic intoxication.** Care is necessary with these inhalations, as they are capable of a caustic effect, as well as of producing reflex spasm of the glottis. Ammonia, pure or associated with carbolic acid, has been employed in the treatment of **acute affections of the air-passages** (Smee, Hagen), in cases of **asthma** (Trousseau); and it is in part to the ammonia produced by combustion that the sedative action of the vapors of datura stramonium and of belladonna is attributed.

NITROGEN MONOXID (NITROUS OXID)

Nitrous oxid (N_2O) has been employed especially as an anesthetic, but it should receive consideration here because it has also been used for other purposes. It is a neutral, colorless gas, like oxygen maintaining combustion, and it has been employed experimentally in all cases in which oxygen itself has been employed. It is a constituent of the 'compound oxygens' and similar mixtures exploited by charlatans, and within recent years applied, with some degree of success, in legitimate practice. It is useful to reduce the proportion of oxygen in air inhaled (see page 315), and to dilute oxygen for medicinal use.

Technic

Compressed nitrogen monoxid—pure, or mixed with oxygen—is obtainable in cylinders with inhalation apparatus attached (see figure 56, page 304), or it may be drawn into rubber bags holding a definite quantity and furnished with an inhaling nozle, or with a valved mask or mouthpiece admitting air. A convenient apparatus for the conjoined administration of oxygen and nitrous oxid for prolonged anesthesia in surgical operations is shown in figures 62 and 63.

Effects

Nitrogen monoxid does not combine with the red blood-corpuscles, but is dissolved in the plasma, and is therefore irrespirable. On this theory attempts to use nitrous oxid by inhalation ought to be useless; but the gas, in addition, exerts an obvious and marked influence upon the nervous system, causing diminution of sensibility to pain, a tendency to gaiety (whence the name 'laughing gas'), ringing in the ears, derangement of vision, a sense of prickling, of subjective heat, of elongation of the limbs, which appear unsteady, and acceleration of the pulse, which becomes smaller.

Therapeutics

It is without doubt this action upon the nervous system that explains the good results obtained by various writers in cases of **paralysis** (Beddoes); in the presence of **affections of the nervous system** (Riadore), in certain states of **nutritive impairment** (Davy), and in **whooping-cough** (Cohen). It is somewhat more difficult to explain the good results reported from its use in infectious diseases, such as **typhoid fever, erysipelas,** and **measles** (Shuman).

Lavison recorded a case of recovery in **miliary tuberculosis** under

inhalations of five gallons of the gas daily at intervals. In the last-named affection—assuming the diagnosis to be correct—it may be supposed to act by reducing morbid hyperoxygenation; but the hypothesis is not entirely satisfying. Klikowitsch has had favorable results from inhalations of nitrous oxid in **chronic pulmonary tuberculosis.**

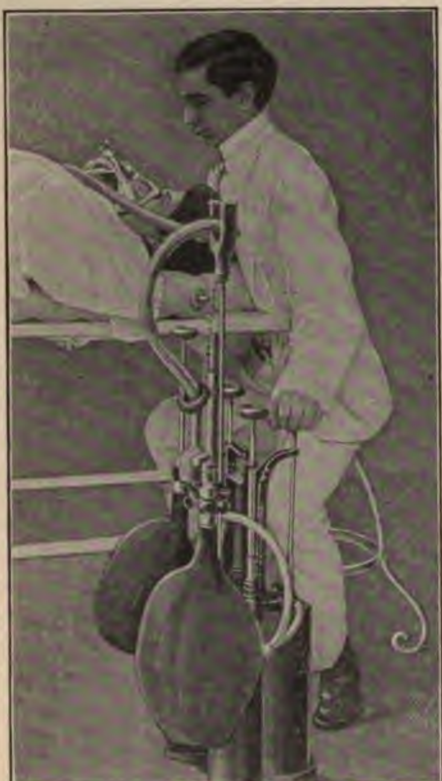

FIG. 62.—CONJOINED ADMINISTRATION OF OXYGEN AND NITROUS OXID.—(*Howard Hospital, Philadelphia.*)

FIG. 63.—APPARATUS FOR CONJOINED ADMINISTRATION OF OXYGEN AND NITROUS OXID.

He adds 20 per cent. of oxygen. J. Solis-Cohen has for many years used this agent in **pulmonary** and **laryngeal tuberculosis** as a sedative. He gives from one to three gallons of nitrous oxid mixed with an equal or a double quantity of air—usually near bedtime in order to procure sleep free from harassing cough. The gain in weight and other improvemen' ' he attributes to the rest thus obtained. The editor resorts

to inhalations of nitrogen monoxid, pure or mixed with air or with oxygen in various proportions, to relieve excessive nervous irritability in cases of advanced pulmonary tuberculosis, as manifested by cough, dyspnea, or insomnia; and has incidentally noted reduction of fever, confirming also the observation of Klikowitsch, that it always renders respiration slower and deeper, while in many cases the pulse diminishes in frequency and increases in force and volume. As a stage of excitation often precedes the stage of sedation, the editor finds the antipyretic as well as the hypnotic effect to be greatest when the daily dose of eight gallons is divided into two portions—the first administered between 10 and 11 A. M., and the second between 4 and 5 P. M. In cases of **irritative and nervous cough,** acute and chronic, he has seen much relief afforded by inhalations of nitrous oxid (20 to 40 per cent.) and oxygen (80 to 60 per cent.). In a case of **acute bronchopneumonia of influenza,** such an inhalation may be given for ten or fifteen minutes, every third or fourth hour.

CHAPTER III

INHALATION OF FUMES AND VAPORS—APPARATUS AND METHODS

Definitions—Fumigation. General Methods of Administration—Inhaling Terminal; Method of Inhalation; Time and Duration of Sittings and General Precautions. Inhalation of Substances Volatile at Ordinary Temperatures—Classification of Methods; Special Apparatus—Respirators; Nasal Inhalers; Bubbling Apparatus; Biegel's Mouthpiece; Inhalation Pipe, Narghile. Inhalation of Substances Volatilized by Heat—Apparatus; Special Fumigations. Absorption of Vapors.

The terms **fumes** and **vapors** are often used interchangeably. It is difficult, moreover, to draw sharp lines of distinction between gases, vapors, and fumes; the more so, since hitherto refractory gases, such as oxygen and hydrogen, have been liquefied and even solidified. Without attempting an impossible exactitude, and following in the main the ordinary usage of the English language, we shall in general understand by **vapors** the tenuous emanations that arise from either liquids or solids at ordinary temperatures, or from liquids under the influence of heat; and by **fumes,** the emanations given off by heated solids, more especially when the substance heated undergoes partial combustion. When, however, solid substances are volatilized by the aid of hot water, and their emanations thus inhaled together with the aqueous vapor, it would be uselessly awkward to refer, *e. g.*, to the fumes of opium carried up by the vapor of water. Similarly, a solid substance such as menthol or camphor, volatile to some extent at ordinary temperatures, and quite volatile under moderate heat, is so closely related chemically and even physically to the essential oils that it seems less pedantic to speak of its vapor than of its fumes. Moreover, one is accustomed to speak of the fumes of certain inflammable liquids, as fluid tar; and to employ the term **fumigation** whenever combustion directly enters into the process of liberation of the vaporous substance. Hence, strict consistency must not be looked for; and, moreover, vapors and fumes will be studied together. It may be said—although to this rule there are many exceptions—that fumes are in general denser than vapors, and more frequently visible.

It may be noted in passing that the term 'fumigation' was for a long time the only one applied to the procedure now described as inhalation, and, according to good French authority, should not be applied—in that language at least—to the absorption of smoke, but should properly be used to designate the inhalation of vapors. Among the ancients, who rarely employed gases, the vapors of liquids that emitted a sort of steam or reek, and dry vapors, giving only little smoke, were chiefly in vogue. Moreover, at that time the generic name of this mode of therapeutics was not nicely limited to absorption by the respiratory tract, as may be noted from the fact that fumigation by steam was used locally in the treatment of hemorrhoids, dysmenorrhea, and other affections, while in the English tongue at present the term is more often applied to external applications, and one speaks also of disinfecting apartments and objects by fumigation.

GENERAL METHODS OF ADMINISTRATION

The vapors inhaled may be either cold or warm, depending upon the temperature at which the substances employed volatilize in sufficient volume for therapeutic use. As a rule, not without exceptions, **warm** vapors are to be preferred in **acute affections of the upper air-passages;** while in **chronic affections,** those given off at ordinary temperatures are better. Warm-water vapor in particular is apt to cause a soggy condition of the mucous membranes, and is thus **counter-indicated** in tuberculosis and chronic inflammations in general.

FIG. 64.—INSPIRATION THROUGH FUNNEL-SHAPED TERMINAL.

Penetration, and hence absorption of vapors and fumes, is to some extent dependent on the form of **inhaling terminal** made use of. J. Solis-Cohen points out that instead of employing a mouthpiece to be inserted between the lips, it is often better to have the inhaling tube terminate in a wide funnel-shaped orifice to be placed in front of the mouth (Fig. 64). The latter form is well adapted to mere inspiration, while the former often leads to a combined effort at suction that interferes with the process, and is, moreover, fatiguing to debilitated and bedridden patients.

At this place may also be quoted the following acute remarks of the same author concerning the **method of inhalation**: "The correct method of inhaling gases and vapors from an inhaler must be **acquired** by the patient, otherwise the vapor will merely be drawn into the mouth and reach the pharynx, and if it mixes at all with the air in the lungs, will do so by diffusion; but with a little effort the manner of effecting penetration into the lungs can readily be acquired. That it is no easy matter to inhale a vapor, and that, consequently, when stramonium and the like are smoked, instead of being carried into the lungs by the inspiratory current, they impress the system sympathetically or otherwise by their effect upon the mucous membrane or the terminal nervous distribution of the pharynx, can be made evident by attempting to inhale the smoke from an ordinary cigar. As usually smoked, none of the smoke passes the glottis, and when the attempt to inhale is made, it will be found to require considerable effort, and will induce a paroxysm of cough with disagreeable sensations, even in the persons of inveterate smokers. A volume of smoke can be retained in the mouth for a considerable time without embarrassing respiration; and this is proof positive that inspiration of air is being carried on behind the velum through the nares. When the nostrils are compressed, the effect is different.

"If the smoke, after having been taken into the mouth, be blown into a wide-mouthed vessel—a tumbler, for example—and a deep inspiration be made of the smoke as it is playing about in the receptacle, the lungs will become charged, under subjective phenomena promptly perceptible to the patient. When, therefore, vapor has been drawn into the mouth from an inhaler, a deep inspiration should follow the suction effort, so that the air, in entering the lungs, will carry a portion of the vapor with it. If this cannot be done, the vapor or smoke may be blown into a tumbler and inhaled from that. When the vapor is forced into the mouth mechanically, by compressed air, from a compression bellows for instance, it can be inhaled much more readily than by the mere effort of aspiration. This method is of advantage in administering inhalations to debilitated or bedridden patients. Care must be taken to keep the compressing apparatus in good order, so that it shall not suck up any of the fluid instead of forcing air through it.

"The importance, then, of seeing that patients inhale correctly is self-evident, for if they are merely directed to inhale, and not taught how to do so effectually, in many instances the attempt will be futile, and the method, of course, fall into disrepute.

"One great mistake often made in administering inhalations is

in having the water from which the vapor rises too hot. Usually a temperature of from 110° to 120° F. is all that is requisite to disengage the volatile ingredients of vegetable substances; and the greater the volatility of the substance to be used, the less the degree of heat that will be required."

Time and Duration of Sittings and General Precautions

When the medicinal agent is unirritating and not toxic, the patient may be kept in the medicated atmosphere, or under its influence, indefinitely, by diffusing the vapor through the air of an apartment, or by the use of a respirator—Yeo's (see Fig. 68) or some similar device—to modify continuously the air of respiration. Otherwise the inhalations are to be administered at such intervals, and continued for such periods as, on the one hand, the nature of the agent, and, on the other hand, the urgency of the symptoms, the special object in view, and other factors of the individual case, may indicate. Sittings may thus **last** from five to fifteen minutes, and be **repeated** at intervals varying from half-an-hour to several days.

Medicinal inhalations are best given **before eating**; if nauseating, they are then less likely to cause emesis, or if stimulating, are most serviceable in provoking appetite. Patients should remain indoors for at least fifteen or twenty minutes after an inhalation, longer if warm vapors have been used.

INHALATION OF SUBSTANCES VOLATILE AT ORDINARY TEMPERATURES

The inhalation methods with **substances volatile at ordinary temperatures**—to which in discussing special medicaments, I shall at times refer more particularly in order to indicate those most available in the special instance—can be reduced to a small number of classes: (1) **Respiration in a chamber or cabinet** in which the air holds the medicinal vapor in any desired proportion. (2) The **direct inhalation** of vapors through the nose or mouth, from the vial containing the volatile substance. (3) The use of **cones or funnels** leading the vapors toward the mouth or nose. These may be of any material not affected by the medicament employed; paper answers in most cases. (4) The use of a **compress** saturated with a volatile liquid, which is held before the mouth. A glass or rubber funnel containing cotton and covered at its mouth with a piece of gauze, may be included here, rather than under the next head. (5) The use of **special inhalers or respirators,** consisting

of **masks, pipes** (Fig. 77), **cigarette-tubes** and the like (Fig. 65), of which a great many forms can be had. (6) The use of a **Woulff bottle** or other **bubbling apparatus.** A simple form (Fig. 75) consists of a flask or bottle closed by a cork through which pass two tubes, one dipping down to the bottom of the contained liquid, and admitting air, while the other is kept a greater or less distance above the level of the fluid, and through a bend carries off to the mouth air charged with the medicinal vapors. (7) The use of **nasal respirators** which are inserted into the nostrils, in cases in which it is desired to reach only the nasal mucous membrane.

FIG. 65.—EVANS'S INHALER.

SPECIAL APPARATUS

Some forms of special apparatus may be described briefly; first I shall call attention to two ingenious methods of **diffusing vapors through an apartment.**

Apparatus of various kinds have been devised to keep up a constant draught of air in a receptacle containing volatile medicaments. One of the best of these is a fan turned by clock-work, causing a current of air to play upon a rope of lampwick suspended from a porcelain dish containing the desired medicament. Hassall has devised a compact portable 'chamber inhaler' consisting of a long cotton fabric so woven as to afford a very large extent of surface for evaporation, which is spread out in several layers, one above another, by means of an arrangement consisting of a double series of rails attached to a box and lifting out and in. The smaller size is 8 × 11 inches. The cloth is saturatd with a solution of carbolic acid, or whatever drug be employed, which volatilizes at the temperature of the apartment.

Respirators

Langenbeck's respirator (1861) was designed at first as a prophylactic device to prevent the entrance of noxious gases and dust. Afterward it was used therapeutically. It consists of a hollow sphere pierced

by two openings. Within the sphere is placed absorbent lint or cotton, saturated with some volatile substance. When in use, the respirator is grasped by the lips, at about its central part.

Masks.—Since then, masks have been used for the most part. They are employed in certain trades to prevent the entrance of dust into the respiratory tract. **Henrot's mask,** used for this purpose, consists of a concave piece of metal, fitting over the mouth and nose, its edge being covered with a hollow rubber cushion to insure perfect adaptation to the face. At the center of the mask is a metal sieve. The apparatus is held in place by means of cords tied about the head.

FIG. 66.—CURSCHMANN'S MASK.

Curschmann's mask (Fig. 66) is of the same general form, except that it is supplied with an anterior chamber closed in front and behind by wire screens. In this chamber is placed a pledget of absorbent cotton impregnated with the medicament, so that the patient inhales the medicinal vapor with an admixture of air.

FIG. 67.—HAUSMANN'S MASK.

Hausmann's Mask.—Hausmann has introduced an improvement in the form of two lateral valves for expiration (Fig. 67).*

* This improvement on Curschmann's mask is claimed by Lazarus.

The perforated zinc respirator described by J. Burney Yeo, of London (1882), is one of the most useful, as it is one of the simplest, devices for the inspiration of medicinal vapors. As will be seen from the illustration, it is simply a little cage of perforated zinc bound with cloth or chamois skin, carrying a sponge or cotton pledget and fitted with elastic loops to attach it around the ears, so that it fits over the nose and mouth. The respired air becomes impregnated with the vapor of any volatile medicament dropped upon the sponge; and as the light and cleanly apparatus can be worn for prolonged periods, a **continuous medication** of the respiratory tract is thus affected. The apparatus of Darenberg, Reynal, and O'Connor differ but slightly from the types already described.

Fig. 68.—Yeo's Perforated Zinc Respirator.

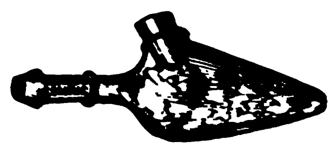

Fig. 69.—Pomeroy's Inhaler.

The **divided mask** of MacNeill Whistler has two superimposed compartments, thus the medicinal vapor enters the nose during inspiration, while expiration is performed through the mouth. This apparatus is of great service, not only in **tuberculosis of the larynx,** but also in **pulmonary tuberculosis.**

Nasal Inhalers

Inhalers especially constructed for the nose have also been used. The simplest plan is to introduce into the naris a plug of cotton, not too tightly compressed, containing the volatile substance in its center. The inspired air takes up the vapor of the drug.

The importance of nasal inhalers has not been sufficiently emphasized, not only do they compel the patient to breathe normally, that is to say through the nose, but they are the means of producing veritable **respiratory gymnastics,** useful not only in slight lesions of the larynx, trachea, and bronchi, but also extremely useful in bringing about the cure of **tuberculosis.** I consider the nose preferable to the mouth for inhalations, and use it whenever possible. I would lay stress upon this advantage of the nasal over the buccal route.

Feldbausch's apparatus acts as a respirator only in so far as it holds

the nostrils open; it thus resembles that of Smithuisen, which in shape may be likened to a cuff-button.

Iankau's inspirator (1897) is constructed, for lightness, of vulcanized rubber. It is made in two general forms, olive-shaped, or in the form of a cone 1.25 to 1.5 centimeters long, and from 0.75 centimeter to 1 centimeter in its widest diameter. The inspirator is hollow. One orifice, a half centimeter in diameter, is at the apex, while the second opening, a little smaller, is placed laterally. It is introduced into the nose by its smaller end, the lateral opening corresponding then to the normal nasal orifice. Once in position it is invisible, and causes neither disfigurement nor discomfort. It may be kept in place for a long time. It is easily removed by pressure on the alæ of the nose. Iankau's instrument may be used as a simple respirator, or for the introduction of volatile drugs; for the latter purpose, there is to be

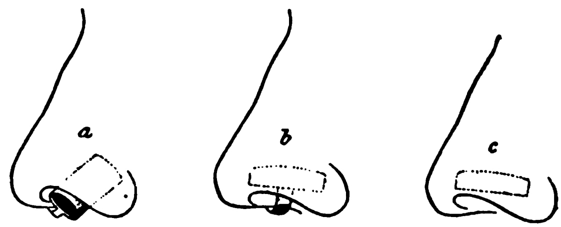

FIG. 70.—FELDBAUSCH'S NASAL INHALER, THREE FORMS.

placed in the inhaler a pellet of bibulous paper soaked in a solution of the drug desired—menthol, guaiacol, oil of turpentine, and the like.

Among the many other forms of intranasal inhalers I shall mention only those which have been designed by **Veylinski.** The first is made of two hollow pieces fitting the circumference of the nostrils and held in place by means of a triangular red-rubber band which barely covers the tip of the nose. The apparatus may be attached by bands tied about the ears or by a spectacle spring across the bridge of the nose. The wearing of this respirator is rather troublesome.

To avoid this discomfort Veylinski had constructed for each nostril a hollow metal piece of exactly the configuration of the vestibule of the naris, in which it fits nicely. Once introduced these pieces therefore have no tendency to be displaced. The anterior and posterior ends of the inhaler or, more correctly, of each inhaler—for the two pieces are independent—fit into the interior and posterior culs-de-sac of the nostrils respectively. This small but elegant device does not disfigure the nose, is well borne, and is easily removed by slight

pressure on the side of the nose. In the hollow of the instrument may be placed pellets of cotton soaked in any desired medicament. I use indifferently the apparatus of Iankau and that of Veylinski.

Many forms of **external apparatus** have been devised for the inspira-

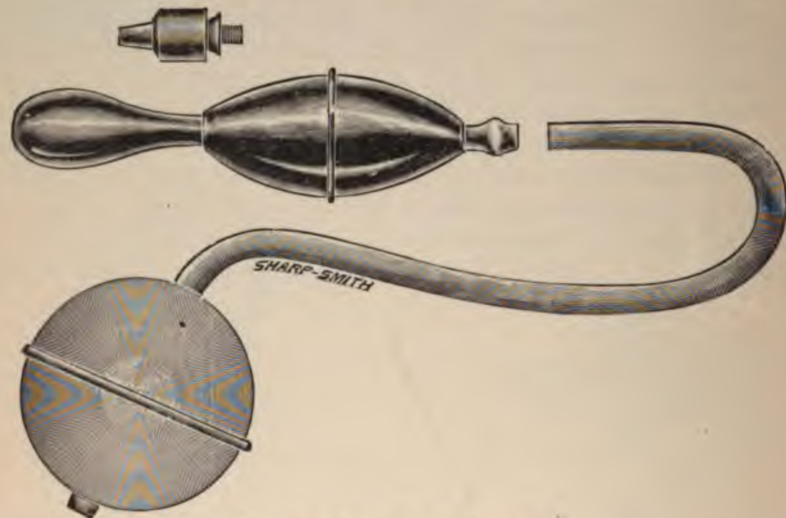

FIG. 71.—INHALER OF BUTTLES.

tion through the nostrils of medicinal vapors. The simplest is a tube, open at both ends, into which the drug may be introduced in crystals or powder, if solid; or, if liquid, poured upon a sponge or a pledget of cotton. The most obvious improvement is to cover this with a case, or with caps, so that it may be carried in the pocket. Of the many more elaborate devices but one need be mentioned.

FIG. 72.—PYNCHON'S MODIFIED TIP FOR BUTTLES INHALER.

The inhaler of Buttles (Fig. 71) was originally intended for inflation and was to be operated by either the patient or the physician. **Pynchon** devised a **tip,** shown in figure 72, to permit the attachment of the inhaler to the cut-off of a condensed-air reservoir, and later enlarged upon his modification so as materially to augment the uses of the instrument. The cone-shaped tip (Fig. 73) may be used either in the

nose or in the mouth, the expanded portion, in the latter case, being placed between the lips with the concavity against the teeth. The tip is made hollow, for the reception of a sponge saturated with a fluid volatile medicine. With this attachment the Buttles inhaler may be used to produce **alveolar hyperdistent'on**; to practise **Politzerization** or **catheterization** of the **Eustachian tube**—when the small extension (a) is to be introduced in the opening a the conical end; and as an **inhaler** for the administration of any desired volatile substance. The union (b) is designed for use with an ordinary atomizer bulb, when the air-tank and cut-off are not available.

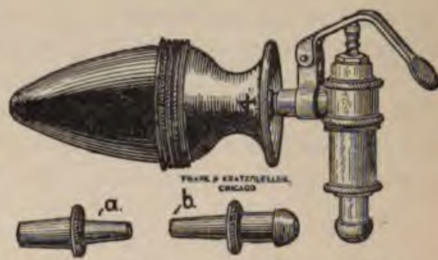

FIG. 73.—CUT-OFF INSERTED IN BUTTLES INHALER FOR POLITZERIZATION, ETC.

Pomeroy's Inhaler (Fig. 69, p. 346) is a modification of the instrument of Buttles, made with a **glass reservoir** to permit the use of agents that would act upon hard rubber. It can likewise be used as a simple tube inhaler.

FIG. 74.—WOULFF-BOTTLE INHALER.

FIG. 75.—SIMPLE MODIFICATION OF WOULFF-BOTTLE INHALER.

Bubbling Apparatus

Since the liquids used in this method volatilize at relatively low temperatures, the inhalers may be quite simple.

A **Woulff bottle** with three openings may be employed (Fig. 74). Through the middle opening the active drug, pure or diluted, which is to fill about one-fourth of the flask, is introduced. The opening is then

closed with a stopper. The two lateral openings are closed with perforated stoppers. Through one of these a tube passes down into the liquid and admits the air. The third opening admits another tube, which does not reach quite to the level of the liquid. This tube is bent and conveys the air, charged with the active vapor, to the mouth. A rubber bulb attached to the air-tube will drive the vapor over when for any reason the patient's inspiratory effort does not suffice.

An ordinary wide-mouthed bottle with a doubly perforated stopper through which the tubes pass as above described, may be used for the same purpose (Fig. 75).

FIG. 76.—MANDL'S INHALER OR FUMIGATOR.

Mudge's inhaler is more ingenious. It consists of a pewter mug furnished with a hollow handle, which communicates by its lower extremity with the interior of the vessel. The latter should be filled up to a point just above the attachment of the handle. A number of perforations in the upper portion of the handle admit the air. The vessel is closed by a cover with two openings. One is for a tube with a mouthpiece for inhalation, the other is furnished with a ball-valve of cork and allows the escape of expired air, the valve opening only on expiration.

The second opening may be dispensed with by attaching to this apparatus, as is done with **Mandl's** (Fig. 76), a mouthpiece that is arranged for both inspiration and expiration. The form designed by **Beigel** is in current use (Fig. 78). The two valves for the passage of the medicated vapors and the escape of the expired air, respectively, consist of very light plates of vulcanite affording perfect occlusion. This does away with the necessity of expiring through the nose, or of frequently removing the tube from the mouth.

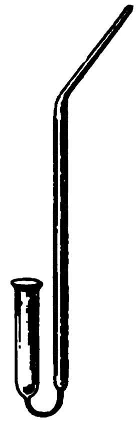

FIG. 77.—INHALATION PIPE.

Scudamore, like J. Solis-Cohen, insists upon the necessity of using large tubes, and of having above the liquid a spacious air-chamber for the mixture of the vapor and the air. He has constructed upon these lines an apparatus which in principle differs but slightly from Mudge's inhaler.

It is important for the patients to take inhalations of unmedicated air from time to time.

Morell Mackenzie's **eclectic inhaler** was designed for use with substances requiring heat for their volatilization, as well as with those volatile at ordinary temperatures. It is rather complicated, but a more simple, portable affair has been constructed on the same principle by Martindale. This consists of a reservoir somewhat widened in its upper half, into which the volatile drug or medicated water is poured. Into the liquid is introduced a funnel perforated at some distance from its extremity by a series of apertures. Through the upper part is inhaled the air, which does not reach the apertures in the funnel until after it has passed through the liquid. The liquid being poured in at the desired temperature, its rapid loss of heat is prevented by enveloping the apparatus in a woolen sack.

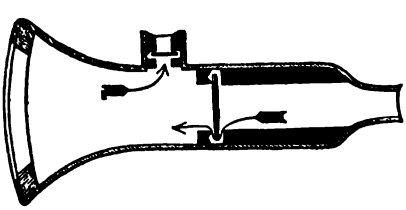

FIG. 78.—BEIGEL'S MOUTHPIECE.

Numerous other forms of apparatus have been suggested; none of which differs in principle from those described. One of the most practical is an **inhalation pipe** (Fig. 77) with a rather narrow opening on top, in which the tube for aspiration is placed rather high, so that one can put in the bottom a certain amount of liquid. The **narghile** of Oriental smokers may likewise be utilized, both with substances requiring combustion,

and those volatile at ordinary temperatures. The relative novelty of the method is an attraction to certain patients.

INHALATION OF SUBSTANCES VOLATILIZED BY HEAT

For the inhalation of substances volatilized by heat—the ancient **fumigation**—some form of apparatus is always necessary. The method is a very old one, the best proof of which is its persistence in certain religious rites. The use of incense in the ceremonies of the Catholic Church is an instance. It is the symbol of purification. The vapors or fumes may (1) be **diffused** through the air of a room or cabinet in which the patient respires; or (2) be **directed** by tubing, by a cone or funnel, or even by so simple a means as the clasped hands, into the nose or mouth of the person inhaling.

As in the case of gases and of substances volatile at ordinary temperatures, complex or simple apparatus—various forms of masks, nose-pieces and mouthpieces, wash-bottles and the like—may be utilized; and in discussing individual agents, these will be described or referred to when necessary. In general, the apparatus consists of two parts: (*a*) for the application of **heat,** and (*b*) for the **respiration** of the fumes or vapors. **Volatilization** may be effected by the use of a metal, glass, or porcelain strip, bowl, or spoon, on or in which the medicament is heated or burned; or a sand-bath, or a water-bath, or some other device with lamp and receiver. Or the vapor of water may be utilized in connection with the volatile medicament, in which case the latter is thrown into, or poured upon the surface of, hot water in a bowl, jug, or special inhaler on the principle of a Woulff bottle. The latter may also be kept warm by direct application of heat from a lamp or other source, or by the intermediation of a water-bath. Reference has already been made to the general form of the **directive** apparatus.

SPECIAL APPARATUS.

Many of the instruments described for inhalation of substances volatile at ordinary temperatures may also be utilized with medicaments requiring heat for their volatilization. Thus Mudge's, Mackenzie's, Martindale's, and the like may be used with water previously heated or may be placed over a source of heat. An ordinary pitcher will answer, if it gives a sufficient surface of water, say a diameter of not less than four or five inches, and an air-space of at least four inches above the level of the hot water. An inverted funnel of glass or rubber

(metal becomes heated and may burn the lips), a cone of paper, or a towel is applied over the mouth of the pitcher to direct the vapor into the patient's mouth (Fig. 79). The expired air escapes beneath the cone, or the patient from time to time uncovers his face. Cohen employs by preference the special inhaler shown in figure 80. A glass vessel of one quart capacity, into which one pint of cold water is to be introduced, is provided with a rubber stopper pierced by two openings one inch in diameter, through which pass large glass tubes; one, the air-tube, dips well beneath the surface of the liquid, and has a funnel-shaped extremity through which the medicament may be poured when the water is heated; the other merely passes into the neck of the vessel, and is bent for the attachment of a flexible (rubber) tube of large caliber, which carries a mouthpiece. The glass vessel fits into a hollow tin holder, previously filled with cold water (water-bath). The apparatus may be placed on a kitchen stove or heat be applied beneath the tin vessel in any convenient way. The illustration shows a gas-stove. When a sufficient temperature is reached—about 140° F. (60° C.)—the flame is extinguished, the medicament added, and the patient inhales. If the water of the bath does not preserve the heat for the ten or fifteen minutes of a sitting, the lamp or gas-stove may be lighted again; but this is not usually necessary.

FIG. 79.—INHALATION OF HOT-WATER VAPOR WITH THE USE OF PITCHER AND TOWEL.

When heat is applied simultaneously with the inhalation, the simplest, as it is the earliest, method is to have the patient inhale over a receptacle placed on an alcohol or gas lamp. In this popular procedure which is readily extemporized, the patient's head is loosely wrapped in a towel, thus allowing the admixture of air; the method is especially used for the inhalation of aromatics. Its great disadvantage lies

in this: the expired air escapes from beneath the towel with difficulty, and if the treatment is kept up long enough, the patient finishes by inhaling his exhalations; besides, the head soon becomes wet with perspiration and condensed vapor.

Hippocrates had already devised an improvement in the form of an apparatus consisting of a pot, with an opening in the lid in which was placed a reed permitting the vapors to issue forth. This mode of application is utilized to-day, except that the cover is replaced by

FIG. 80.—COHEN'S HOT-WATER VAPOR INHALER WITH WATER-BATH ON GAS-STOVE.

an inverted funnel. **Bullock's inhaler** is made of sandstone; the lid and the tube, the extremity of which is covered with rubber, are made of tin. Its disadvantages are: the overheating of the tube by the vapor, which may be remedied by lengthening the tube; and the difficulty experienced by patients, especially during their first attempts, in inhaling through a tube introduced directly into the mouth. Other simple modifications are readily suggested. Thus the illustration (Fig. 81) on page 355 shows a simple and convenient apparatus terminating

in an oro-nasal mask of special shape, which may be made of any suitable non-conducting material.

Mandl's inhaler or **fumigator** consists of a globular glass vessel with two tubulures. (See Fig. 76 on page 350.) One allows the introduction of the medicated solution, and is left open to admit the air; the other gives attachment to a long, flexible tube, at the end of which is a mouthpiece; between the tube and the mouthpiece is interposed a wooden connection to prevent overheating. The globe is heated with an alcohol lamp. An important improvement consists in closing the orifice which admits the air and allowing the admixture of air and vapor to take place at the mouthpiece.

FIG. 81.—SIMPLE MODIFICATION OF THE HIPPOCRATIC INHALER.

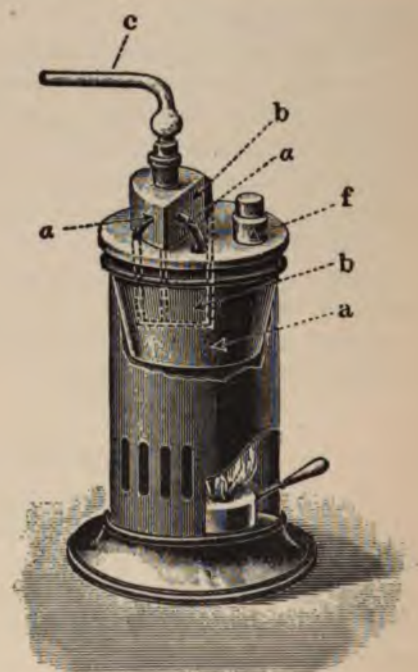

FIG. 82.—SCHREIBER'S APPARATUS FOR THE INHALATION OF VAPORS.

a, Water-bath; b, receptacle for medicament; *a*, tube for water-vapor; c, delivery tube; f, covered inlet.

It is thus possible to regulate the quantity of air added, and to cool the vapor effectually. It is important to breathe slowly and deeply, and to advise patients not to breathe as one would puff a pipe, because then the buccal mucous membrane only would be reached. Quite frequently I have been obliged to direct patients to hold the nostrils shut before they have succeeded in inhaling correctly.

Schreiber's apparatus consists of a double boiler, the larger of about

200, and the smaller of about 80, cubic centimeters' capacity. The former contains water to be heated by an alcohol lamp; the two terminate in the same shaft. The method is highly practical where it is not desirable or not possible to mix the substance to be employed with water.

Lee's inhaler is a simple apparatus for producing vapor, which dispenses with the necessity for respiratory effort.

Special Fumigations

In addition to the methods detailed in the foregoing pages, there are certain special forms of fumigation, in which either the active medicament itself or some substance yielding it is subjected to **combustion,** and then inhaled directly; or vapors or fumes are generated in considerable quantity about the person or bed of the patient and inhaled or absorbed from the atmosphere; thus, **mercurial fumigation** by vaporization of calomel; the disengagement of watery vapor containing **lime,** by slaking the latter within a croup-tent; and the various **sedative fumigations** that have retained their popular vogue in the palliation of **asthma.** These will be described in connection with the study of the individual agents.

ABSORPTION OF VAPORS

Vapors, like gases, readily penetrate into the air-passages. Obstacles may arise: (1) from their **temperature**; (2) from their **irritating effect** on the mucous membrane of the respiratory tract. We have studied in the discussion of aërotherapy the application of **hot and cold air.** At this point we shall concern ourselves with vapors only, especially **steam.**

Above a certain temperature, the vapor of hot water causes a disagreeable, almost intolerable, sensation, and if its action be sufficiently prolonged, will give rise to a burn of the mucosa, the consequences of which are usually very serious—as in boiler explosions. Even very hot aqueous vapor (70° to 80° C.—158° to 176° F.), however, may sometimes be inhaled, provided the patient be placed far enough from its source to permit a sufficient admixture of air. Again, the experiments of Bloch and Paulsen, on the temperature of the air in the nasal fossæ, and the observations of Mosso and Rondelli, among laborers in lime-kilns, have shown that when hot air or vapor has been inhaled, its temperature is rapidly reduced by the evaporation that takes place in the upper air-passages.

The second and more important obstacle to the penetration of vapors into the air-passages is **irritability of the mucosa,** depending essentially upon the nature of the remedy employed. As in the case of gas, it is important that a considerable proportion of oxygen be present in the mixture inhaled. During fumigation by **combustion** methods it must be remembered that there is a possibility of the penetration of fine particles of carbon.

CHAPTER IV

MEDICAMENTS SUITABLE FOR USE AS VAPORS

(A) Substances Volatile at Ordinary Temperatures—Ether; Chloroform; Ethyl Bromid; Ethyl Iodid; Ammonium Chlorid; Camphor; Menthol; Pyridin; Amyl Nitrite; Tar; Benzene; Phenol; Creosote; Aniline; Turpentine; Terebene; Eucalyptol; Myrtol. (B) Substances Volatilized by Heat—Iodin; Bromin; Mercury; Arsenic; Silver Nitrate; Pine Resins; Glycerin; Resorcin; Water; Balsamics. Special Fumigations; Niter Paper, Stramonium, Belladona, Tobacco, Hashish, Opium, Coca.

(A) SUBSTANCES VOLATILE AT ORDINARY TEMPERATURES

While we do not include in this study the absorption of vapors administered to produce surgical anesthesia (chloroform, ether, ethyl bromid, etc.), nevertheless something should be said of the inhalation of these same vapors when employed for direct therapeutic purposes, local or general.

ETHER ($C_4H_{10}O$)

Administered in small quantities, more or less frequently repeated, ether produces—in a healthy subject—a transitory excitation, a sort of restlessness, a more or less intense gaiety, a hyperexcitation of the memory and of the imagination. Pushed a little further, but not to the point of inducing unconsciousness, it exerts an antispasmodic action.

It has been **employed** in the most varied affections of the respiratory passages; in certain acute affections, *e. g.*, **capillary bronchitis** (Gadberry) and **pneumonia.** Formerly considered as one of the best abortive agents in the treatment of the latter disease, it proved disappointing to Skoda, and has been abandoned for that condition. In **tuberculosis** (Beddoes, Clark) it is sedative to the cough, and makes expectoration easier; it has been recommended for **asthma** (Scudamore), **chronic bronchitis, diphtheria, coryza,** and **hysterical aphonia.** In some cases other

agents have been used in conjunction with ether, the effect being conjoint; thus **cicuta** leaves have been steeped in it (Pearson), and **conium, camphor, musk, iodin, opium** and other drugs, both stimulant and sedative, have been added in various forms

The great **objection** to the employment of ether is 'ether mania,' the imperious desire to repeat the inhalations, which appears quite soon, especially in certain subjects. Chronic intoxication leads to gastro-intestinal troubles and to a progressive intellectual deterioration.

CHLOROFORM ($CHCl_3$)

Administered as an anesthetic, chloroform causes, before the appearance of muscular relaxation or of anesthesia, a suspension of the cerebral functions, a sort of sleep (Durck).

It is this sedative action which, in certain cases, meets a very definite **indication.** Chloroform-inhalation has been extolled for convulsive affections—**epilepsy, hysteria, chorea, eclampsia, tetanus,** and **pertussis.** I have often employed it to relieve **suffocative seizures** accompanying paralysis of the dilators of the glottis,—such as may be caused by tuberculosis, dilatation or aneurysm of the aorta, emphysema with hardening of the right lung, adenopathies, and the like,—and, in general, in **laryngeal and tracheal stenosis** with attacks of suffocation. I have thus been able in many cases to avert tracheotomy, as the method is effective in diminishing to a singular degree the intensity and duration of the acute asphyctic crises. For this it suffices to inhale a few drops of chloroform poured upon a compress, as in giving it for purposes of anesthesia, after the manner described in my treatise on laryngeal tuberculosis published in 1889. This treatment has been recommended for a long time in all spasmodic affections of the air-passages (T. Churchill, Baumgartner). Chloroform has also been recommended in certain **acute nasal catarrhs** in the early stage (J. Solis-Cohen) and in **pneumonia** (Hutava, Malmsten). It is also used in small quantities to mitigate the irritating qualities of other vapors and for continuous respiration with the instrument of Yeo. B. W. Richardson lauded **ammoniated chloroform** as an antiseptic agent.

The employment of chloroform as a sedative agent has been **objected** to because of the well-known fact that chloroformization is sometimes followed, even at the beginning, by grave and even fatal accidents. Here, however, we are dealing with inhalations of very small quantities. I have never observed the slightest accident in any of the numerous applications I have made or prescribed.

ETHYL BROMID (C_2H_5Br)

Ethyl bromid has been employed in the treatment of **hysterical crises** and **epilepsy.** It is rare that one can check the convulsion, the administration being usually too late. Bourneville and d'Ollier, by regular inhalations of small quantities of ethyl bromid extending over a period of six to eight weeks, have succeeded in reducing very distinctly the number of seizures.

ETHYL IODID (C_2H_5I) (HYDRIODIC ETHER)

The vapor of ethyl iodid is to be inspired mixed with air. The effects of iodin are modified by the action of ethyl, and it is thus in considerable degree a sedative. It is easily decomposed by light or heat, becoming inactive. Half a fluidounce, which is about one ounce by weight, may be dispensed in an amber-colored bottle wrapped in dark paper. When the patient is moving about, he can carry the little vial in his vest-pocket and take a few whiffs of the vapor from time to time. Under other circumstances it should be kept in a cool place. The drug must be chemically pure or it soon becomes worthless.

Uses.—In any case in which the local effect of iodin upon the air-passages is desired, or in which it is necessary to get a constitutional iodin-effect, without resort to the stomach, the inhalation of ethyl iodid offers a convenient and effective means of accomplishing the purpose. It is thus of use in **syphilis,** and especially in cases of syphilitic inflammation or ulceration of the nose, mouth, and throat. It is of great benefit in **tuberculosis of the larynx,** and in **pulmonary tuberculosis,** at any stage of the disease, but especially when local stimulation and disinfection are desired (Cohen.) In subacute and chronic **nasal catarrh,** in some cases of **hay-fever,** in **subacute laryngitis** and **subacute bronchitis,** and in **chronic laryngitis** and **chronic bronchitis,** when a sedative, sorbefacient, and disinfecting agent is desired, inhalation of a mixture of equal parts of terebene and ethyl iodid often gives satisfactory results. Ethyl iodid is highly useful in **ozena** and in **fetid bronchorrhea.** It has been employed with apparent benefit in **asthma** and in **acute croupous pneumonia** (Bartholow) and **acute bronchopneumonia** of various types. In one case of **whooping-cough** in an adult, in the editor's practice, it was apparently of service.

Administration.—Ethyl iodid may be inhaled directly from the vial or a few drops may be placed on a pledget of cotton held to one nostril, or to the lips; or five or six drops with a teaspoonful or two

of water may be placed in a wide-mouthed bottle or jar, where the liquid ether, being heavier than water, sinks to the bottom, the vapor gradually rising and diffusing through the air in the receptacle; or ethyl iodid alone, or mixed with terebene, alcohol, creosote, chloroform, menthol, thymol, or any combination of these or similar agents, may be dropped upon cotton or a sponge in a Yeo respirator or S. Solis Cohen's resistance valves. As the drug is expensive and highly volatile, methods that restrict its diffusion are usually to be preferred. Some patients can inhale the vapor of ethyl iodid for ten or fifteen minutes without experiencing unpleasant effects; others feel slight vertigo after inhaling for a minute or two. Five minutes is the usual time. To get the full benefit of the drug it must be used frequently and persistently; thus, in pulmonary tuberculosis the daily inhalations are kept up for two, three, or more years (Cohen). In cases of active disease, the inhalations are sometimes practised as often as every half hour; in convalescent cases, or in cases of tuberculosis not showing active progress, the intervals are proportionately lengthened.

AMMONIUM CHLORID (NH_4Cl)

This has been used heretofore chiefly in the form of dry vapor. Inhalations of nascent ammonium chlorid are to be preferred. If one pours into a vessel containing five to six grams (1 to 1½ fluid drams) of water of ammonia one to two grams (15 to 30 minims) of hydrochloric acid, white fumes of ammonium chlorid are produced, and may be inhaled. A convenient form of apparatus, especially for use in nasal cases, is S. Solis Cohen's modification of Lewin's inhaler (Fig. 83). The important features are the use of a rubber bulb to drive over the ammonia and acid vapors and the size of the wash-bottles. The vapors mingle in a large quart wash-bottle half-filled with water, there forming ammonium chlorid vapor, which is driven—mixed with air—into a second equally large bottle containing acetated rose-water, where it is again washed and any excess of ammonia neutralized. In this second wash-bottle, terebene, eucalyptol, myrtol, creosote, or other volatile drug may also be placed. Waldenburg, Fuchs and Liebermann (1875), Nothnagel, Rossbach, and Lasèque have made use of ammonium chlorid vapor with success in the treatment of **acute bronchial catarrhs** and of **acute exacerbations** of chronic catarrhs; it has proved of great service in **pharyngitis sicca** and in **chronic rhinitis** attended with diminution of normal secretion and formation of crusts (J. Solis-Cohen); at times also in **chronic laryngitis,** and in **chronic nasal catarrh** attended with profuse mucopurulent discharge.

CAMPHOR ($C_{10}H_{16}O$)

The inhalation of camphor, which since the publications of Raspail has been a popular treatment for **tracheal and laryngeal affections,** was recommended even by Avicenna. It is accomplished by inhaling air through a tube containing fragments of camphor. It causes a sensation of coolness which some patients find quite agreeable, but which gives place, when the inhalation is continued, to an oppressive feeling, and to a slight diminution of the blood-pressure. Japanese camphor is chiefly

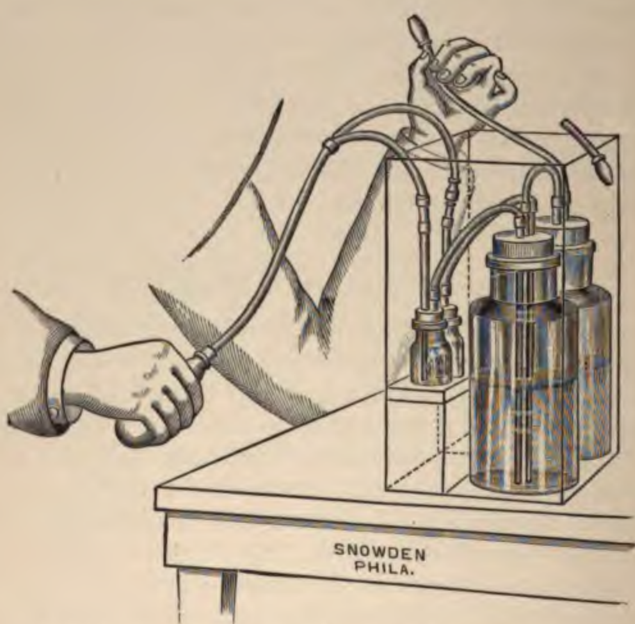

FIG. 83.—S. SOLIS-COHEN'S AMMONIUM CHLORID INHALER.

used, drawn from the laurus camphor. The inhalation of **camphorated steam** for **coryza,** etc., will be referred to in another connection.

MENTHOL ($C_{10}H_{14}O_4$)

This is found chiefly in the essence of mint from China and Japan, but also in the European and American products. It is employed principally for inhalation in **affections of the air-passages.**

Physiologic Effects.—Menthol causes a sensation of cold, followed by

one of gentle warmth. The sensation of cold is not the result of rapid evaporation, for it is not produced by other volatile oils; menthol appears to have a selective action on the thermal nerve-endings (Goldscheider, Blin). After a while there is produced an anesthesia of moderate duration, with analgesia—because of which Liebreich classed menthol among the anesthetics. It causes, moreover, a reflex stimulation of the secretory nerves. It is, besides, an excellent antiseptic, and MacDonald especially has insisted upon the bactericidal action of its vapors.

Mode of Employment.—Menthol inhalations are administered in various ways. The drug may be used **pure,** and is then placed in a receptacle—a cigarette-holder or any little tube open at both ends suffices—through which the air inspired is drawn. This method has its warm advocates. Another method consists in dissolving the menthol **in oil**—which takes up one-fifth of its weight of the drug—and painting the back of the throat with this solution. The menthol enters the lungs with the inspired air, and imparts a sensation of coolness to the chest, accompanied by ease of respiration. One may also use **alcoholic solutions,** which may be poured into an empty receptacle, or, better still, into one containing warm water (Figs. 79, 80, 81). Lastly, use has recently been made of powerful atomizers, capable of throwing a finely divided oily solution of menthol into the larynx itself.

Indications.—As I have employed menthol more often than any other remedy in the treatment of the affections of the upper air-passages, I believe that I can state very exactly the indications for its use.

It has been recommended in **acute affections of the nasal passages** (Bishop, Wünsche), and for the relief of these conditions there are quite generally on sale so-called 'catarrh powders' of which the active principle is uniformly menthol; in **hay-fever** (Wainwright); in **influenza,** against which even a preventive virtue has been attributed to it (Lennox-Browne); in **acute and chronic affections of the pharynx and retro-pharynx** (Hartmann); in **acute laryngitis;** as a palliative in **tuberculous laryngitis** (Rosenberg, J. Solis-Cohen, Bechay); in **acute and chronic tracheitis;** and in **pulmonary tuberculosis** (Aronson, Carasso and others).

An experience of more than fifteen years has taught me that in **nasal affections** menthol by inhalation is rarely effective, while its local application in powder, ointment, or oil is usually of service. In acute or chronic **painful affections of the pharynx** inhalations of menthol, as a rule, succeed in allaying the pain better, and for a longer time, than any other remedy. It is ineffectual in phlegmonous tonsillitis and in herpetic tonsillitis; on the other hand, painted on or inhaled, its curative action in **acute follicular tonsillitis** is truly remarkable. It

is the best curative remedy in **acute catarrhal laryngeal inflammations**; in **grippal laryngitis** it relieves distress, without the aid of other treatment, and it hastens recovery. It is a very valuable agent in the treatment of **diphtheria,** but I cannot consider it—as some authors seem to hold—a specific. Of real service in **acute** and **subacute tracheitis,** it is but rarely useful in **bronchitis,** and I have never seen definite results from its employment in pulmonary tuberculosis, asthma, or fetid bronchitis. It may be combined as a **sedative corrigent** with irritating solutions to be inhaled or applied topically to the air-passages.

PYRIDIN (C_5H_5N)

Most of the smokes used for the relief of the dyspnea of asthmatics contain principally pyridin. This led Sée and Rochefontaine to experiment with this principle itself. Pyridin is a colorless liquid, with penetrating odor, and very volatile.

Its **effect** on dyspnea is to be explained by a moderating influence on the reflex activity of the bulbo-medullary centers. The effects of pyridin inhalation appear very rapidly; the dyspnea is lessened, expectoration is rendered fluid, and the patients often manifest a desire to sleep.

Indications.—It is in many cases, the agent *par excellence* for relief of the **asthmatic** paroxysm or, to be more exact, of **paroxysmal dyspnea**—including true asthma, gouty asthma, emphysematous asthma, and similar conditions—but it has the great drawback of possessing a disagreeable odor; it often fails, even in asthma; and it may be **dangerous** when the cardiac action is feeble and there is obstruction in the circulation (stasis). Thus, there have followed its employment, headache, vomiting, tremors, and even syncope.

Administration.—It is sufficient to pour four or five grams (say a teaspoonful) of pyridin into a saucer placed in a corner of the patient's room, the doors and windows of which should be tightly closed. A **sitting** should last fifteen to twenty minutes, and if more than temporary relief is desired three sittings may be held each day.

AMYL NITRITE ($C_5H_{11}NHO$)

The value of this drug has not yet been thoroughly appreciated, in spite of its widespread employment in certain conditions and of the articles by Hayem setting forth its great usefulness. Administered by inhalation it is of considerable activity, and, used with reasonable precautions, it is free from danger.

It seems almost audacious for me to write this, but I beg leave to relate a little anecdote bearing upon the subject. Asking the chief druggist at La Pitié one day, when I had assumed charge of the medical service there, for a bottle of amyl nitrite, in order to try it on one of the patients, the druggist himself brought me the precious bottle. While handing it to me he felt constrained to warn me of the extreme toxicity of the drug. I let him have his say, and moistened freely a compress which I held before the patient, who inhaled it without ill effect. But the druggist had fled; thinking I must be mad, he had run to warn the superintendent.

To show what a terrible reputation amyl nitrite has gained I quote from authorities: two to five drops, say Nothnagel and Rossbach; three drops only and with care, says Dujardin-Beaumetz. Lauder Brunton contents himself by saying that it is an extremely dangerous substance. Thus quotations might be multiplied.

Physiologic and Toxic Effects.

What are its physiologic effects, and what, according to various authors, is its toxicity? The principal effects of amyl nitrite inhalations manifest themselves in the nervous and circulatory systems (Guthrie, Lauder Brunton, Eulenburg and Guttmann, Pick, Filehne, Mayer and Friedrich).

Nervous Phenomena.—The first inhalations cause a feeling of dullness in the head, a sort of mild intoxication. The patient staggers when he attempts to walk. The pupils are dilated. Small objects appear surrounded by a luminous ring, yellow near the center and bluish-violet at the periphery (Pick). There is a feeling of distress, due largely to vascular phenomena. All these symptoms are ephemeral. According to my observation among a large number of patients, most of these symptoms, particularly the distress, do not reappear on renewing the inhalations, and the visual disturbances are very inconstant.

Veyrierès has observed after larger doses vertigo, headache, and stupor; but one must take into consideration that he experimented upon himself, and allowance must therefore be made for a certain amount of error due to suggestion. Among animals, if the dose be increased, one may observe agitation, followed by violent **tetanic convulsions.** After the period of convulsion, due to the excitation of the cerebral centers, there follows **muscular relaxation,** and finally cessation of respiratory movements and asphyxia without spasm,—**paralysis of cerebral centers.** There is a **fall of temperature** of central origin (Bourneville). To kill a rabbit requires 0.75 gram (12 minims) by inhalation.

Circulatory Phenomena.—Much more important, from a therapeutic viewpoint, are the circulatory phenomena. Amyl nitrite causes **peripheral vasodilatation,** not by stimulation of the bulbar centers, as claimed by Filehne, nor reflexly, but by direct influence upon the walls of the blood-vessels (Lauder Brunton, Mayer and Friedreich, Amez-Droz, Huchard, Dugau). It is an active vasodilatation, for the dilated blood-vessels may be made to contract again by stimulating the vasoconstrictor nerves (Dugau). The vasodilatation varies in different individuals, sometimes appearing in the face, again upon the sides of the chest, and again upon the abdomen. Sometimes it remains limited to the face, the neck, and upper part of the chest. Physiologic experiments have demonstrated that the viscera, with the exception of the eye, where the conditions of pressure are peculiar, and the lungs (Filehne) are the seat of vasodilatation. Pick is of the opinion that amyl nitrite acting locally on the capillary walls, should influence last the vessels of the lungs, since it does not reach them until it has traversed the circulatory tract. In fact, however, as soon as it is inhaled, it is immediately taken up by the pulmonary veins. The arterioles of the lungs are, then, affected least, and only when the inhalation is prolonged. Some authors indeed assert that the nitrites cause constriction of the pulmonary vessels (H. C. Wood, Jr.).

The vasodilatation causes a marked **decrease in blood-pressure** and an **acceleration of the heart-action** which do not in any degree come from enfeeblement of that organ. I have found irregularity of the heart action noted by observers only as an exceptional effect and among emotional subjects.

In animals, **respiration** is accelerated and increased in depth; it is only on forcing the drug that respiration slowly diminishes and becomes superficial; it is always regular. In human beings Pick has noted only that the **respiration becomes easier**; I may add that it is made deeper and, if previously irregular, becomes rhythmic.

Amyl nitrite appears to diminish the oxygen-absorbing power of the hemoglobin, the blood of animals poisoned with very large doses being black (Wood); but this effect is only transitory (Jolyet and Regnard), for the corpuscle undergoes no alteration (Hayem). After the ordinary use of the drug in therapeutic doses, there is no change in the color of the blood.

There is regularly an increase in the **urine,** following the administration of amyl nitrite; and sometimes there is transitory glycosuria.

Administration.—Since the toxic dose for rabbits is 0.75 gram (12 minims), it is an exaggeration of timidity for writers to advise two or

three drops by inhalation, to be used with all the precautions necessary for dangerous drugs. In fact, the necessary dose is much larger than this, except with subjects who are more than usually susceptible. Inhalation apparatus is not needed; a tube containing a bit of absorbent cotton on which are poured several drops of amyl nitrite may be used; but a handkerchief answers every purpose. One pours on at first some ten drops of pure amyl nitrite, which will not redden blue litmus paper, and brings the inhaler near the mouth of the patient to accustom him to the penetrating odor of the drug; from time to time he is allowed to breathe pure air; then several drops are again poured out, and at the end of fifteen to thirty seconds the desired effect is obtained. As the patient becomes accustomed to the treatment, the duration of the inhalations may be lengthened and the number of drops increased. But from the first one may use twenty drops, and even more, with proper precautions. I have known patients to take eight or ten inhalations daily and absorb, therefore, a very considerable dose. The doses, moreover, vary according to the case.

Indications

Amyl nitrite has been used in all cases in which there is **spasm of the blood-vessels.** For use in emergencies patients are furnished with glass **perles,** each containing a dose, which can be crushed in a handkerchief.

Conditions Associated with Spasm of the Blood-vessels of the Brain.—Not as a curative agent, but as a means of aborting the attacks, amyl nitrite is useful in **migraine** with pallor of the face; in **epilepsy** with initial pallor; and in **eclampsia.** In epilepsy, for which it has been extolled by Bourneville, it does not always prove effectual. This is because in certain cases there is no spasm, but primary vasodilatation,—duskiness or flushing of the face. In **hysteria** (Aireton) it exercises no beneficial action other than by suggestion.

Conditions Associated with Spasm of the Peripheral or Visceral Blood-vessels.—It has been lauded for **malarial chills, sea-sickness** (Clapham), **chloroform- and chloral-poisoning,** and, above all, **angina pectoris.** It is generally conceded that in this last affection, for which it has been recommended by Brunton, Amez-Droz, Bourneville, and, more recently, by Huchard, it effects in most cases a disappearance of the pain and of the distress.

Mode of Action in Angina Pectoris.—It acts by diminishing the increase of blood-pressure resulting from spasm of the peripheral arteries (Lauder Brunton). To this explanation, Huchard objects that increase

of tension is not the only cause of the angina. That is true, but it does not prove that in the anginose attack the spasm of the arteries is not often a causal element of the greatest importance. It must be stated, on the other hand, that, according to Johnson, general contraction of the arterioles is caused by the pain (the excitation of the central extremity of a sensory nerve). Another objection urged by Huchard is that all cases of angina pectoris are not caused by arterial spasm. However, the explanation of Lauder Brunton appears to me more acceptable than that of Johnson, who regards amyl nitrite as an antineuralgic, or that of Huchard, which is but a modification of the same view. Amyl nitrite increases the myocardial circulation, which has been hindered by spasm or stenosis of the coronary arteries, and lessens the resistance to the work of the heart by lowering the blood-pressure.

As to other indications, I have but to repeat those given by other authors; but in the following cases the credit for its employment belongs to Hayem; In **idiopathic paroxysmal tachycardia,** when the pulse becomes imperceptible during the attack, or the extremities become cyanotic, or the urine is suppressed, amyl nitrite diminishes the duration and the intensity of the crisis. In **pulmonary tuberculosis,** for which it has been tried on a large scale by Hayem, without ever having the slightest ill effect, amyl nitrite considerably relieves the dyspnea, but its effect upon the progress and ultimate issue of the disease is unfortunately *nil*. This is not to be said concerning its use in **active congestions** of the lungs and in **pneumonia.** Here amyl nitrite is certainly the remedy of election, especially so when it is used in fairly large doses. Administered from the beginning, at the stage of congestion, it may abort the development of the lesion. Used later in the disease, it relieves dyspnea, greatly facilitates expectoration, which becomes more fluid, and hastens resolution. As to its **mode of action in pneumonia,** several theories present themselves: First, that it is due to the active dilatation of the capillaries of the lungs, which, however, as physiologic experiments on animals show, appears late and is but slight in degree. It is indeed asserted with some experimental proof that the nitrites act oppositely upon the pulmonic and the general circulation. This is possible, although it must be remembered that the conditions in a man with pneumonia are entirely different from those presented to the experimenter by a normal animal. Second, that it acts by stimulating diuresis and the elimination of the toxins. Pharmacodynamic study of the drug makes this theory worthy of consideration. Lastly, that it lessens the work of the heart by lowering the blood-pressure. Here we recall that heart failure is the great danger in pneu-

monia. Perhaps no one of these explanations alone is correct, and perhaps some other explanation must be sought. I am, therefore, not prepared to lay down its mode of action, but I do insist that the existence of this beneficent action of amyl nitrite in pneumonia appears to me, after a study of more than a hundred cases, to be beyond question; Bartholow, B. W. Richardson, and S. Solis Cohen also hold this view and have reported cases in point.

The **counterindications** to the use of amyl nitrite, as given by other writers, are: chronic congestion of the viscera, especially of the brain; atheroma; and even hysteria.

PHENOL (CARBOLIC ACID) (C_6H_5OH)

This remedy has been employed by inhalation in **fetid bronchitis** and in **gangrene of the lungs** both as a palliative and in the attempt to cure (Leyden, Nothnagel and Rossbach). We shall refer later to its use by atomization. In the two conditions mentioned it has given undoubted good results, but in the treatment of **pertussis**—for which certain proprietary preparations consisting chiefly of crude carbolic acid are largely exploited—it has proved a failure. In **fetid** affections, as in certain forms of **laryngitis,** it often suffices, in order to obtain amelioration, to inhale the vapor of a few drops of carbolic acid poured on cotton or wool; the form of apparatus being unessential. The same measure has been advised in **laryngeal** and **pulmonary tuberculosis,** but for these affections creosote is better. For some years the inhalation of carbolic acid has enjoyed a reputation in the **abortive treatment of acute coryza.**

Carbolic acid is likewise among the substances employed with the vapor of hot water in the treatment of **acute** and **subacute laryngitis.** (See page 383.)

The following is one of the formulas most often used:

Carbolic acid,	10 parts
Oil of turpentine,	5 "
Ammoniac,	12 "
Alcohol,	20 "

BENZENE (BENZOL) (C_6H_6)

Benzene has been recommended in **pertussis** and in **tuberculosis** (Tschernow). In pertussis the method consists in sprinkling the patient's bed with the benzene, which is then inhaled with the air.

ANILIN (C_6H_5N)

Anilin inhalations administered by causing air to bubble through a solution of the drug are said to have afforded some success in the treatment of **tuberculosis** (Kremianski).

SUBSTANCES VOLATILE AT ORDINARY TEMPERATURES BUT ALSO USED WITH HEAT

There are many substances, including the phenol, terebinthinate, and balsamic groups of agents, and various essential oils, which, while volatile at ordinary temperatures and so used, are also frequently employed in connection with the vapor of **hot water,** or in some other method involving the use of heat. I shall refer here to a few of the more important that have not yet been mentioned.

TAR

In France two products are known under this name (*goudron*). One is the residue from the distillation of coal—mineral tar, coal-tar; the other is the result of dry distillation of the conifers—wood-tar, or vegetable tar.

Mineral tar is composed of hydrocarbons, of oxygen compounds, and of ternary bases of the pyridin series. It is rarely used by inhalation; its derivatives—benzene, phenic acid, creosote, pyridin, and the like—being more often employed.

Vegetable tar has been employed for more than a hundred years in the treatment of various **affections of the bronchi.** In many subjects there is no doubt that it is of some benefit (Gubler). The air of the patient's room is saturated with tar-vapor by means of special apparatus known as 'goudronnières,' of which there are various kinds—cylinders supplied with a spiral groove, apparatus with pans, and others. Cigar-holders in which are placed tubes of blotting-paper impregnated with tar are also employed.

The use of vegetable tar in the treatment of **tuberculosis** is worthy of mention if only for its historical interest; 'vapors of tar, made warm and diluted with oil of turpentine,' were employed by Edward Jenner,—his object being to kill thereby the parasite to which he attributed the disease, and which he supposed to be akin to, if not identical with, that of hydatids. He compared tubercles to the oak-apple or gall-nut, or to the mossy excrescence that springs from the wild rose or sweetbrier, these being due to 'insect-

irritation.' Tar vapor was likewise recommended by Rush, whose method was to boil together equal parts of tar, bran, and water. Beddoes relates a case in which exposure to the emanations of tar in a warehouse was of great benefit. Crichton dissolved a quantity of tar in water, and added potassium carbonate to neutralize the 'pyroligneous acid,' slowly boiling the mixture over a spirit-lamp, and taking care that it boiled and did not burn. J. Solis-Cohen says: "I have frequently seen benefit from the vapors of tar in cases of advanced phthisis. In recent inflammations and in the hectic fever of phthisis its use requires caution, as it is said to induce congestion, and may thus give rise to hemorrhage or severe inflammation." His method is to mix prepared tar with water until it is soft, and place it in an iron saucepan nearly filled with water, over which is fitted a tin cover terminating in an elbow of piping. The pot is heated upon the fire or over a gas flame or alcohol lamp, and the vapors are diffused through the room. For direct inhalation of tar an apparatus at one time much used in Philadelphia consists of a tin vessel of about a pint capacity for holding water, into which fits a shorter tin cup for receiving the tar. The latter is tightly covered with a lid pierced with air-holes and provided with a delivery-tube. The vapor is evolved by heat. Delmis, finding inhalation of tar fumes impracticable, used troches of tar which were allowed to dissolve in the mouth. He believed that the emanations would thus be inhaled.

Of recent years tar has been almost entirely superseded by creosote, which is more convenient and equally efficacious; except that it is not so stimulating as is the tar.

CREOSOTE

Creosote has long been used by inhalation, pure or vaporized with water at 60° C. (140° F.) (Elliotson). It is among the agents found useful in **acute** and **subacute laryngitis.** (See page 383.) Mandl has recommended it in warm vapor in **chronic tuberculous bronchitis** with scant secretion, and dry, spasmodic, and distressing cough. His apparatus consists of a bulb containing the creosote in watery solution, warmed over an alcohol lamp (see Fig. 76 on page 350), connected by a tube with a terminal directing the creosote vapors toward the mouth. This is Mandl's formula:

Creosote,	5.0	parts
Acetic acid,	50.0	"
Water,	500.0	"

Into the bulb is put a teaspoonful of the mixture and about 60 c.c. (two fluidounces) of water at each time, and this is increased according to the tolerance of the patient.

Gimbert vaporizes over a water-bath small doses of creosote, which are increased until 30 grams (one fluidounce) are used each night. His idea is that by this means complete absorption is obtained; and that the drug enters the blood through the pulmonary parenchyma, producing both local and general antisepsis. In cases of **pulmonary tuberculosis** S. Solis Cohen employs creosote for continuous inhalation by means of the Yeo respirator; it may be used undiluted or mixed in various proportions with chloroform, alcohol, eucalyptol, ethyl iodid and the like. One should make sure that he obtains pure **beechwood creosote.** Chemically pure **guaiacol** may be employed similarly.

TURPENTINE AND ITS CONGENERS

Turpentine, the various **oils of pine, terebene, eucalyptol,** and **myrtol,** may for our purpose be considered together. They are absorbed in a state of vapor by the mucous membrane of the respiratory tract in sufficient quantity, not only to act locally, but also to produce constitutional effects. They are employed at times in dry inhalation at air temperature, but also in hot atomization suspended in steam, and in fumigations.

Administration.—The action of the turpentine **liniments** is to be explained, not only by the local action of the oil, but also by the inhalation of its vapors.

According to Ireland, the air of pine forests contains large quantities of ozone produced by the reaction of light and air with the terebinthinate emanations; and he suggested that by living in a room or conservatory filled with pine saplings patients might derive similar benefit, which he attributed to the action of ozone or antozone on the blood. J. Solis-Cohen has seen much good follow the practical application of these suggestions. Fresh pine boughs may from time to time be placed in the patient's bed-room and sitting-room, or the attempt be made to grow pine saplings in the house. While they retain their vitality a certain amount of vapor is given off. Pillows may be filled with pine needles, renewed from time to time, or sprinkled with pine oil.

At the Flinsburg Sanitarium the guests pass half an hour morning and evening in rooms the air of which is impregnated first with salt solution, then with the essence of pine-needles, and then with that of balsam fir, ten minutes for each. This is followed by a bath and

a walk. The benefits are both local and general, and twenty years of experience have confirmed the efficacy of the inhalation of resinous emanations as a tonic measure. It has been suggested that shallow tanks filled with pine-needles and fir twigs, with a stream of water trickling through them, on the principle of salt-evaporating pans, might prove a useful adjunct to city hospitals or spas.

Turpentine may be diffused through the air of the room in any convenient way, its strength increasing with exposure to air and light. It may be sprinkled on the floor of the patient's room, or used with Hassall's or other convenient evaporating device; or shallow pans containing some of the drug may be placed upon the hearth or elsewhere, so that the contents will be subjected to a gentle heat and continuous evaporation take place. If greater heat be necessary, the oil may be thrown upon water that has been brought to something less than the steaming-point, or evaporated over a water-bath at 60° C. (140° F.).

Turpentine has also been used by **fumigation.** Courtoux advises burning the oil in an iron spoon every half hour in the patient's room. Delthil, who thought he had found the specific for **diphtheria,** burned a mixture of 40 grams (10 drams) of mineral tar and 30 grams (one fluidounce) of oil of turpentine in a metal or earthen pot. In order to avoid the danger of fire, the pot is to be placed in the middle of a large sheet of metal. The patient remains in the fumigating room for thirty minutes, then returns to his own room. The fumigations are repeated every two hours. In the course of a series of experiments in charring different woods to produce a vapor for commercial purposes, Mr. Hamilton E. Smith, of Philadelphia, made the observation that the vapor produced by the partial combustion of **green pine wood,** unlike raw smoke, does not produce a choking sensation; on the contrary, the odor is very agreeable, has an exhilarating effect, and apparently can be inhaled with safety for an indefinite period. He suggests that an apparatus might be devised by which the **vapor from the charring of pine** might be utilized therapeutically. The apparatus represented in figure 84 is simple and comparatively inexpensive. It consists of a pair of peculiarly constructed retorts, one to be used at a time so that the flow may be continuous; a small spraying apparatus to purify the vapor; and a series of pipes and valves to carry it into any room that may be desired.

For **direct inhalation** of terebinthinate vapors, one may use evaporation from the surface of hot water (see page 383); or, preferably, **steam atomization** of a sufficiently dilute solution (see page 408); or **dry atomization** of an oily solution, say in Oliver's nebulizer (see pages 327 and 406).

Terebene, eucalyptol, various **oils of pine,** of which the best are those of the Scotch fir-tree (*Pinus sylvestris*) and of the mountain-pine (*Pinus Pumilio*), may be used with or instead of turpentine; as may also **myrtol,** a near therapeutic congener. Any of these agents may likewise be employed by direct inhalation, as from the vial, from a

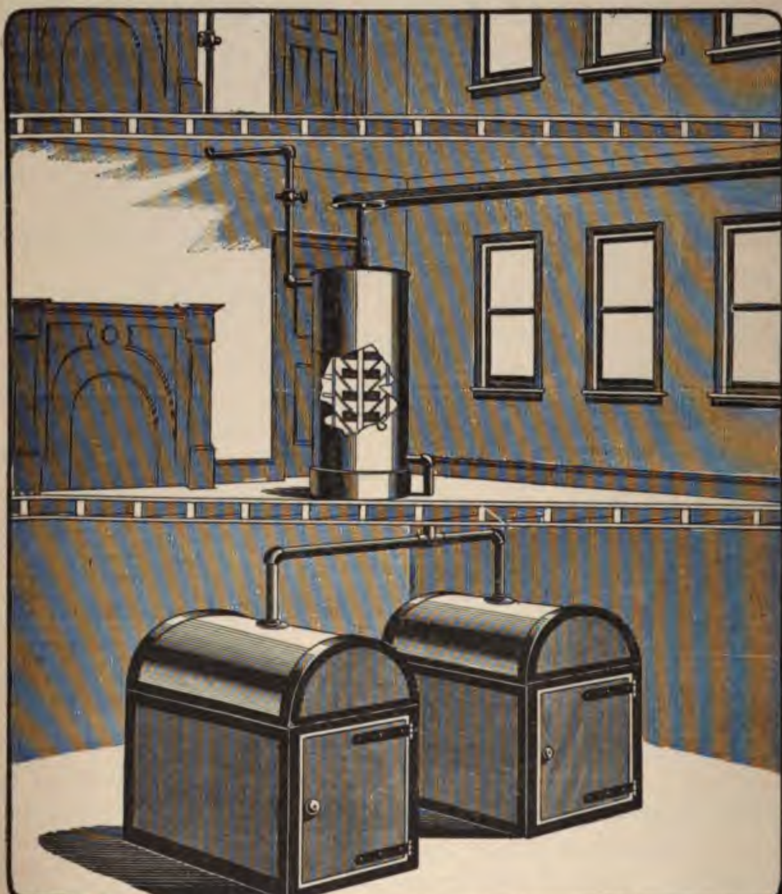

FIG. 84.—SMITH'S APPARATUS FOR THE INHALATION OF VAPOR FROM CHARRED PINE.

pledget of cotton, from the surface of steaming water, or from the sponge of the Yeo respirator; or a sponge saturated with the oil may be inclosed in a bag of cheese-cloth suspended like a locket about the patient's neck. Cohen frequently uses terebene or eucalyptol on the sponge in his compressed-air apparatus, or passes the air through a Woulff bottle con-

taining one of these agents floating on the water. A favorite formula for use with the Yeo respirator is terebene, eucalyptol, ethyl iodid, and alcohol or chloroform, equal parts. Lewin places a few drops of the drug to be used on a piece of cotton in the bowl of a small smoking-pipe, through which the patient inspires for several hours at a time.

Physiologic Effects.—Oil of turpentine is but slightly toxic. Its action in inhalation has been studied especially by Rossbach. From the outset a diminution in the frequency of respiration is noted, then some cough and a feeling of oppression. Applied directly to the mucous membrane of the trachea, it renders the latter pale and increases secretion; but if the air be heavily charged with the vapor, secretion diminishes and finally ceases altogether. In a general way, oil of turpentine reduces the excitability of the central nervous system and of the respiratory and circulatory systems, and causes a fall in temperature (Rossbach). It is a cardiac stimulant, and a general stimulant to mucous membranes, especially at the points of elimination,—the bronchi and the bladder,—but in overdoses irritates, and may thus produce cystitis and strangury, or, by action on the kidneys, hematuria. In medicinal doses it is a distinct hemostatic. **Terebene** is much less irritant; indeed though stimulant to secretions, it is sedative to nervous phenomena, as cough.

Eucalyptol seems to be more actively antiseptic than turpentine; the **oils of pine and fir** are equally stimulating to mucous membranes but less irritating; **myrtol** is more sedative, especially in the presence of spasmodic affections of the bronchi (Cohen).

Therapeutics

Perhaps some of the benefit of turpentine stupes in **pneumonia** is due to inhalation of the vapor, as unquestionably is the case in bronchitis. In addition to **diphtheria** and **whooping-cough,** terebinthinate inhalations have been recommended in **pulmonary diseases.** Stokes, Graves, and Waldenburg have warmly recommended these inhalations for **chronic bronchial catarrh** with dyspnea, for **bronchiectasis,** with or without fetor, and for **bronchorrhea.** S. Solis Cohen recommends them in **chronic pulmonary tuberculosis**; in **asthma** he prefers myrtol, and in **whooping-cough** eucalyptol, to other agents of the group. In **pulmonary gangrene** and in **fetid bronchitis** turpentine has produced not only disappearance of fetor but also the cure of gangrenous cavities. Beyond a direct bactericidal action, it perhaps is able to act upon the oxygen, transforming it into ozone (Rossbach). If used during a febrile period, it acts as an antipyretic. Lewin and Gerhardt in the treatment of **laryngeal and bronchial catarrhs** employ, in preference to tur-

pentine, the oil of *Pinus sylvestris*. The following is the formula of Morell Mackenzie:

Oil of fir (*Pinus sylvestris*),	40 drops
Light magnesium carbonate,	1.20 grams (20 grains)
Water,	30.0 grams (1 fluidounce)

A teaspoonful with a pint of water at 60° C. (140° F.) for five-minute inhalations (six respirations to the minute), morning and evening.

IODIN

Technic.—Laennec, believing that the **iodized vapor** escaping from seaweed was the curative agent in sea-coast atmospheres, attempted to make an artificial sea-air for consumptive patients by heaping varec in their apartments, and especially about their beds. Richardson produced a factitious marine atmosphere by diffusing through the air of the sick-room, at the rate of 2 fluidounces of the solution in fifteen minutes, a steam- or hand-spray of **hydrogen dioxid** (10-volume solution), containing 1 per cent. of **ozonic ether, iodin** to saturation, and 2.50 per cent. of **sea salt.** Piorry, who observed much benefit in tuberculosis from the direct inhalation of iodin, as well as from its internal use, desired his patients not to be deprived of its benefit during sleep, and had several saucers containing it placed about their pillows. In the hospital he attached a number of open vials of iodin to the iron frames supporting the bed-curtains. He stated that under its influence pulmonary lesions diminish in extent, and cicatrization of cavities even occurs; while general nutrition is much improved. Sir John Murray obtained an iodized atmosphere by placing an open capsule containing iodin in a vessel of hot water, or a vessel containing iodin in such a position as to be traversed by a current of steam escaping from a vessel in its neighborhood. Part of the benefit resulting he attributed to the equable temperature thus maintained in the patient's apartments. De Renzi placed a capsule containing iodin in a sand-bath, and volatilized from 6 to 32 grains daily in a room of about 900 cubic feet capacity. Corrigan's apparatus or some modification of it—as, for instance, the use of a chemist's glass funnel with regulating stopcock (see Fig. 59) in place of the globe and wick—is one of the best that can be used for this purpose. A porcelain dish containing water is supported at the proper height above a spirit-lamp, and the medicinal solution drops through a cotton wick from a globe above, into the boiling water in the dish. Scudamore was enthusiastic in the praise of iodin inhalations. He mitigated the irritat-

ing qualities of the vapor by adding a small quantity of tincture of conium at the moment of inhalation. His method was to throw on warm water, in a stoppered vessel furnished with two tubes, from 1 to 4 drams (4 to 16 cubic centimeters) of a solution containing 6 grains (say 0.4 gram) each of iodin and potassium iodid, with 2 drams (8 cubic centimeters) of alcohol in 5 ounces (150 cubic centimeters) of distilled water. The process was repeated three or four times a day. The simple means of vaporizing suitable substances is one of the best, and an inhaler can readily be extemporized. J. Solis-Cohen, who reports good results in the chronic laryngitis of tuberculosis from inhalations of iodin in combination with carbolic acid, points out that much of the benefit derived from painting tincture of iodin over the chest may justly be attributed to the inhalation of the vapor of the iodin, especially when the application is made at night. Leigh, indeed, rubbed iodin ointment upon the chest and into the axillæ, so that the patient could breathe the vapor by placing his head beneath the bed-covering.

Iodin may likewise be employed for direct inhalation in **crystals** which give off the vapor at ordinary temperatures; or in the form of the **tincture,** which may be dropped on the sponge of Pomeroy's nasal inhaler, or be made to volatilize by warming it directly, or by pouring it into hot water; or, again, in slow-burning pastils, which may conveniently be made according to either of the following formulas:

	Grams
Iodin,	0.10 (1½ grains)
Charcoal,	0.50 (7½ grains)
Potassium nitrate,	0.10 (1½ grains)

Mucilage of gum tragacanth, enough to make one pastil.

Or—

	Grams
Iodin,	0.10 (1½ grains)
Benzoin,	0.25 (4 grains)
Balsam of tolu,	0.05 (1 grain)
Potassium nitrate,	0.10 (1½ grains)
Charcoal,	0.05 (1 grain)

Mucilage of gum tragacanth, enough to make one pastil.

I ordinarily use the tincture for all short and repeated inhalation séances, and the pastils when I desire to obtain a certain saturation of the air in the patient's room.

Cigarettes of sea-wrack or **fucus,** advised for consumptives because of the small quantity of iodin which they contain, are prepared from fucus leaves, to which stramonium or sage is sometimes added. Iodin

is also sometimes prescribed in the form of cigarettes prepared with camphor or with sage leaves saturated with tincture of iodin. S. Solis Cohen uses **ethyl iodid** for the production of iodin effects by inhalation (see page 360).

Therapeutics

As noted, the principal use of iodin by inhalation has been in the treatment of **pulmonary tuberculosis,** and having already cited many good observers in its favor, I shall not mention all the authors (Chartroulle, Huette, etc.) whose conclusions are identical, and whose methods of iodin inhalation have nevertheless fallen into disuse, perhaps a little unjustifiably. It is certain that the treatment often fails, but it is a mistake to hold that it favors hemoptysis, which, on the contrary, in patients predisposed to blood-spitting, is soon made to cease. The employment of iodin inhalations was actively combated by Stokes and by Little and is now rarely advocated; but it appears to me that the pendulum has swung too far in the wrong direction. The inhalations should not be regarded as the only active treatment for pulmonary tuberculosis, nor, indeed, as a treatment indicated in all cases, but this much at least I assert positively, that I have many times obtained good results from their use. Iodin inhalations have been used also for **coryza** (Ringer), and in all the **acute,** and especially in the **chronic** (Merril), **affections of the larynx,**—*e. g.*, **diphtheria,**—of the **trachea,** and of the **bronchi.** Used pure or in association with carbolic acid (J. Solis-Cohen), the inhalation of iodin vapors has been highly recommended in the treatment of **tuberculous laryngitis.**

BROMIN

Bromin is supposed, like iodin, to be a constituent of sea-air, and is found in certain springs. It is an efficient disinfectant, and would be useful, I have no doubt, in **tuberculosis.** Too great pungency, however, and its general unmanageableness constitute great drawbacks to its use, while ethyl bromid is too powerful an anesthetic to be used similarly to the iodin-ether. Bromoform has been tried, but it is often too irritating to the conjunctiva to permit persistence in its use. It does not seem to irritate the nose or throat so much. The method recommended by Ozanam for bromin inhalations in **croup** and **diphtheria** would probably be the most available in cases of phthisis in which there was no objection to the steam. Putting into a bowl of boiling water a large pinch of potassium bromid or of common salt, he then

adds gradually, two or three times during five or ten minutes, a teaspoonful of an aqueous solution of bromin, one drop to the ounce. The vessel is covered with a funnel of glass or paper, and the patient inhales the vapor slowly and deeply. Mixed with the steam of the water, it does not produce irritation.

Franck has had constructed an apparatus which directs the bromin vapors against any desired spot. Leuthlen employed in croup a solution of 4 parts each of bromin and potassium bromid in 200 parts of distilled water. A sponge saturated in this solution is held under the nose of the patient for from five to ten minutes every hour. Schütz also recommends it in croup and diphtheria. He employs the same formula, placing the sponge in a cone of drawing-paper and holding it over the mouth and nose as in chloroformization; the inhalation continuing from five to ten minutes, and being repeated every hour or half hour. In the nervous stage of **whooping-cough,** Vogelsang keeps the atmosphere of the patient's apartment impregnated with bromin vapor. **Bromoform** well diluted is even more useful and may at times be employed by direct inhalation for brief periods.

SUBSTANCES VOLATILIZED BY HEAT

MERCURY

Administration.—Either **cinnabar** or **calomel** (Jackson) may be used, the latter preferably after repeated sublimations so as to avoid its irritant effects (Lee). Calomel may simply be heated on a piece of metal, but usually the mercurial vapors are mixed with steam, to accomplish which mixture the very simple and ingenious apparatus of Langlebert or of Bumstead (Fig. 85) is employed. The top of the instrument consists of a cup on an elevated base which is surrounded by a channel for the reception of water. Calomel is placed in the cup and on the application of heat the vapor thus becomes mingled with steam.

FIG. 85.—BUMSTEAD'S CALOMEL VAPORIZER.

Mercury in the form of mercuric nitrate may also be incorporated

in **cigarettes** (Trousseau), or it may be used in **troches** (Polak), or in powders to be **smoked in a pipe.**

BERNARD'S MERCURIAL CIGARETTES

	Grams	
Mercury bichlorid,	0.04	(⅔ grain)
Extract of opium,	0.02	(⅓ grain)
Tobacco leaves freed from nicotin by washing in acidulated and then in pure water,	2.00	(30 grains)

Dry and cut the leaves and smoke them like ordinary tobacco, one or two cigarettes daily.

LANGLEBERT'S TROCHES

	Grams	
Mineral charcoal finely pulverized,	25.0	(6 drams)
Mercury protiodid,	2.0	(30 grains)
Benzoin,	0.5	(7½ grains)

Mix and add enough syrup to make a paste, which is divided into twenty pastils. Burn one morning and evening and inhale the vapor.

Again, a titrated solution of mercury bichlorid may be spread on paper with a brush and allowed to dry, after which a layer consisting of a titrated solution of potassium nitrate is added (Trousseau and Pidoux).

Therapeutics

In the earliest works on **syphilis,** mercury in the form of inhalations is advised as one of the most active measures (Fracastor, Vigo). In ancient times the inhalation of mercurial vapors (cinnabar) was practised in India for certain diseases, in order to produce salivation. In modern times mercurial inhalation has had its advocates, not only in the treatment of syphilis,—and especially of tertiary lesions of the **pharynx** and **larynx,**—but also in the treatment of **croup** and **diphtheria, asthma,** and certain **nasal affections, empyema of the sinuses, polypi,** and **fetid coryza** (Nevins).

The method has been practically abandoned, perhaps without good reason.

ARSENIC

Arsenic was formerly advised for inhalation in **asthma, bronchitis,** and **chronic laryngitis** (Avicenna). It has been used in the form of cones to be burnt in the patient's room, and in cigarettes. In spite of its laudation by Trousseau, the method has found but scant favor.

The following is the formula for the preparation of ten cones (Sarradin):

Arsenious acid,	1 part
Opium,	1 "
Phellandrium,	2 parts
Stramonium,	8 "
Hyoscyamus,	8 "
Benzoin,	8 "
Belladonna,	10 "
Potassium nitrate,	20 "
Gum tragacanth,	2 "
Water,	q. s.

Trousseau's anti-asthmatic **cigarettes** are made as follows:

Sodium arsenate,	1 part
Distilled water,	30 parts

A sheet of filter-paper is made to absorb the solution; it is then dried and divided into twenty pieces, which are rolled into cigarettes in a paper tube.

Baudin's arsenic cigarettes each contain one centigram of arsenious acid.

SILVER NITRATE

The action of silver nitrate fumes was accidentally discovered by a Norwegian photographer, who communicated his observations to Bidenkop. The latter obtained surprising results on submitting his patients every second or fourth day for one or two hours to a séance in a chamber in which he evaporated the silver salt. **Chronic inflammations of the nose, pharynx, larynx, trachea,** and **bronchi,** and especially **emphysema with abundant expectoration,** were favorably modified. Holm confirmed these results, but to eliminate acid vapors, he heated the silver nitrate together with ammonium nitrate. Mygind thinks that it is in **chronic bronchitis** and in **emphysema** that silver nitrate is particularly indicated.

PINE RESINS

Residence in forests of pines and firs has always been held to exercise a beneficial influence on affections of the respiratory passages. It is well known that ozone is present there in relatively greater quantities than elsewhere. We have discussed this subject in connection with the use of **turpentine.**

In addition, it may here be noted that the treatment of **rheumatism** with hot fomentations made with fir shavings is in popular favor in southeastern France. This practice was introduced into Paris by

Chevandier (de la Drôme). Favorable results have likewise been reported in certain **laryngeal** and **bronchial affections.**

GLYCERIN

The inhalation of glycerin vapors, produced by heating fifty to sixty grams (one to two fluidounces) of glycerin in a porcelain cup, has been recommended, but it provokes violent paroxysms of cough.

RESORCIN

Powdered resorcin heated in a metal capsule volatilizes with a white smoke, lacking any definite odor, but leaving a sweet taste on the tongue. The fumigations are to be repeated every two hours, using one gram (15 grains) of resorcin each time. The inhalation does not produce any disagreeable sensation. It rapidly calms the **cough of phthisis** or of **bronchitis.**

THE VAPOR OF HOT WATER (STEAM)

For many years the vapor of water, often incorrectly spoken of as **steam,** has been made use of in the treatment of affections of the mucous membranes of the nose, pharynx, larynx, and bronchi. It is to be remembered that the water is not brought to boiling-point,—100° C. (212° F.),—which would scald, but to 60° C. (140° F.). Its **action** has been compared to that of a poultice, *i. e.*, to the local application of moist heat. It is an active stimulant to lymph and blood circulation and produces abundant diapedesis and cell proliferation. It aids in cleansing the surface of the diseased areas and reduces the congestion of the inflamed regions. In passing, we may point out that the vapor baths, so popular among the ancients and in the Orient, are, in effect, only confined places that combine the action of heat and water-vapor.

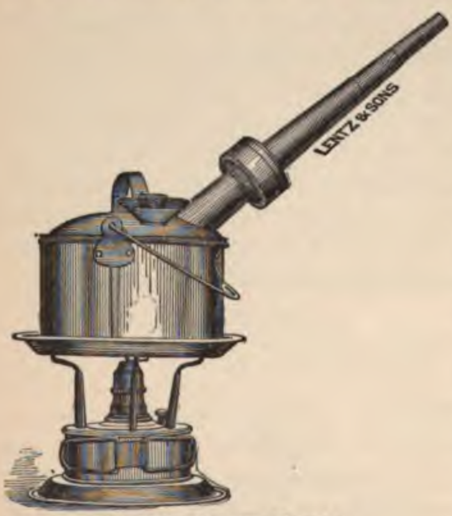

Fig. 86.—Croup Kettle.

Therapeutics

For the reasons stated, the inhalation of aqueous vapor has been recommended in most of the **acute affections of the pharynx and of the larynx.** It has been found especially useful in **croup**; by keeping the children in an atmosphere at all times supersaturated with the vapor of water the suffocative spasms may be relieved, and in some cases the necessity for tracheotomy or intubation may be avoided (Wanner, 1834; Jenner, 1861; J. Solis-Cohen, 1866; Oertel).

Krull had advised the inhalation of hot-water vapor for **tuberculosis,** with the idea of inducing dilatation of the blood-vessels, thus stimulating the pulmonary circulation and consequently the absorption of oxygen. The affected parts were to acquire a greater resistance at the same time that the healing of ulcerated areas was being aided. As these theoretic conceptions, on which the method is based, do not correspond with physiologic facts, the results obtained were not at all what Krull had expected, and his method is to-day forgotten. In fact, moist inhalations are usually harmful in tuberculous affections. In tropical countries, and to a less extent in the countries of southern Europe, it has often been proved that inhalations of aqueous vapor are of the greatest value in soothing **nervous irritability.** Gubler relates that patients placed in damp rooms at the Hospital of Milan never acquired **tetanus,** and that the surgeons who had noticed the same fact employed steam as a prophylactic.

Inhalation of Medicated Water-vapor.—Inhalations of the vapor of water charged with volatile medicinal agents are useful in many conditions. Simple fumigation obtained by raising the temperature of water containing aromatic plants, such as eucalyptus, young shoots of the fir-tree, and the like, still has a certain popular vogue. Its efficacy is due principally to the warm water; although the antiseptic action of the oils, and more recently their irritating effect, have been considered the active agencies; the hyperemia produced by their inhalation stimulates secretion. When emollient herbs are used, there is no doubt that the water-vapor itself is the chief agent; but, according to Gubler, a greater value must be attributed to practice when the water is medicated with fragrant herbs and plants, such as leaves of the linden-tree, orange leaves, and aromatic herbs of the families of umbelliferæ and labiates. These plants, when used by fumigation, have a real antispasmodic action; and this is true to a greater extent of plants containing narcotic volatile substances, such as cicuta, poppy, belladonna, hyoscyamus, and stramonium. Gubler recommends fumigation with water medicated with belladonna leaves at the beginning of an **acute tracheo-bronchitis,** at

the stage when the mucous surfaces are very dry. This procedure also brings relief in the first stage of a serous **acute bronchitis.** The patient's head is wrapped in a towel and he is told to bend over a vessel containing a small quantity of aromatic herbs steeped in hot water. Mudge obtained similar results with ordinary hot water. The use of simple inhalations of water-vapor, with the addition of antiseptic substances,—carbolic acid, thymol, creosote, and the like,—has been almost entirely abandoned, except in acute and subacute inflammations, being displaced by atomization, to which we shall refer later. In **acute laryngitis** or **laryngo-bronchitis,** however, there is no measure of relief comparable to the inhalation of warm aqueous vapor medicated with compound tincture of benzoin and paregoric; a teaspoonful of each being thrown on the surface of a pint of steaming water in a suitable vessel (see figures 79, 80, and 81, pages 353 to 355), and the process repeated every second, third, or fourth hour as necessary. In **subacute** inflammations of the upper air-tract a few drops of creosote or carbolic acid, with eucalyptol or oil of pine and light carbonate of magnesia to assist in carrying up the medicament (see page 376), are usually more efficacious. Inhalation of camphorated water-vapor relieves and sometimes shortens an **acute coryza.**

SPECIAL FUMIGATIONS

In the procedures now to be described resort is had to **combustion** of the medicinal preparation, with liberation of more or less dense fumes which the patient inhales in any convenient manner. Thus certain chemical changes take place, and the actual agent of relief is not always easy of recognition.

POTASSIUM NITRATE (NITER PAPER)

One of the oldest methods of fumigation is represented by niter paper, which was introduced by Nicolas Piso. It is prepared by impregnating paper with a solution of potassium nitrate. This dry paper is burned directly before the patient's mouth. It has been recommended for **asthma,** and it sometimes relieves when stramonium fails. Mackenzie advises its use for **spasm of the glottis.**

Composition.—Gubler holds that from its combustion are produced sedative gases, and among these he especially selects oxygen and nitrogen monoxid as the efficient agents in explaining the action of the paper. In 1860, Eulenburg analyzed the smoke, and found ammonia, carbonic acid, carbonic oxid, and traces of free potassium cyanid.

Koch (1880) determined the presence of finely powdered carbon and of ammonium carbonate, carbonic acid, and water. He could not demonstrate the carbonate, nitrate, or cyanid, of potassium; the presence of carbonic oxid was doubtful. To-day the action of the paper, which contains many ingredients, is attributed chiefly to pyridin.

Mode of Preparation.—The following is **Hager's formula** for making the paper: Take 120 grams (4 ounces) of unsized white paper and mix with hot water to form a paste; squeeze out thoroughly and mix in a mortar with potassium nitrate, 60 grams (2 ounces); myrrh and olibanum, each 10 grams (2½ drams); belladonna, digitalis, and stramonium, each 60 centigrams (10 grains). Spread the mixture out in sheets several millimeters thick, dry, and cut into strips.

Galopin's balsamic cigarettes consist of sheets of paper saturated with the tinctures of tolu and of iris, in addition to the niter mixture. The balsamic cigarettes used for **aphonia** consist of thick blotting-paper dipped in a solution of potassium nitrate, dried, and then covered with compound tincture of benzoin.

DATURA STRAMONIUM

Datura Stramonium, more commonly known as stramonium, is one of the Solanaceæ, the leaves of which are employed in the treatment of asthma of nervous origin. It has been in general use in Asiatic India for many centuries. It is a narcotic, not a hypnotic. Its action is like that of belladonna, but more powerful (Trousseau and Pidoux).

Effects and Uses.—Datura can cause **toxic effects,** although rather exceptionally: visual hallucinations, severe and persistent headaches, and sometimes priapism, and it is not necessary to look to the disturbance of the general circulation caused by the asthmatic spasms, to account for such symptoms when they appear. It is thought that the **sedative effect** of stramonium depends upon the considerable quantity of daturin—an alkaloid isomeric with atropin—contained in the leaves.

In the majority of cases striking results are obtained from its use in **nervous asthma.** This appears to me to be beyond dispute. In asthmatics with emphysema and marked catarrhal bronchitis, the inhalation of stramonium fumes has often been observed to **relieve the spasms of dyspnea** (Sims, 1802; Martin-Solon, Andral, Salter, Varnias, Anderson, Laennec, Trousseau, etc.).

Administration.—For inhalation, the pulverized leaves of stramonium are used—independently or mixed with tobacco, belladonna, etc.—either as anti-asthmatic powders, or in the form of cigarettes. The

formula in the French Codex calls for one gram (15 grains) of the leaves in each cigarette. More complex formulas have also been recommended; *e. g.*, ordinary tobacco wet in a solution containing 5 centigrams (¾ grain) each of potassium nitrate and potassium iodid and 20 centigrams (3 grains) of extract of stramonium. Many proprietary 'asthma powders' consisting largely of stramonium are sold in the shops.

In the same way, and in about the same doses, **belladonna** leaves have been used. Schroeder has recommended their use for hemoptysis. The leaves of **hemlock** (conium) and of **cicuta** and **phellandrium** (water hemlock) have been employed in **chronic bronchitis** and **tuberculosis** (Snow, Stokes), and the leaves of **hyoscyamus** have also been smoked (Pearson). Generally these are combined with stramonium leaves.

The following formulas are types of their kind; the number of such preparations is endless.

FUMIGATION PASTILS

	Grams	
Paste of unsized gray paper,	120.0;	say 4 ounces
Powdered niter (potassium nitrate),	60.0;	" 2 "
" belladonna,	5.0;	" 80 grains
" stramonium,	5.0;	" 80 "
" digitalis,	5.0;	" 80 "
" phellandrium,	5.0;	" 80 "
" lobelia inflata,	5.0;	" 80 "
" myrrh,	10.0;	" 160 "
" olibanum,	10.0;	" 160 "

To be divided into 36 squares, one of which is to be burned each evening in a closed room.

ANTI-ASTHMATIC CIGARETTES

	Grams	
Belladonna leaves,		
Stramonium leaves,		
Digitalis leaves,		
Sage leaves, each,	5.0;	say 1 dram
Tincture of benzoin,	40.0;	" 1 ounce
Potassium nitrate,	75.0;	" 2 ounces
Water,	1000.0;	" 1 quart

Immerse, sheet by sheet, one quire of rose blotting-paper for twenty-four hours. Dry and cut into rectangles 7 centimeters by 10 centimeters, and roll.

ANTI-ASTHMATIC POWDER.

	Grams	
Stramonium,	30;	say 1 ounce
Sage,	15;	" ½ "

To be made into 20 cigarettes or smoked in a pipe (Trousseau).

A fact to be noted in connection with stramonium inhalation is the acquisition of the **stramonium habit** by many asthmatics. Little

by little they increase the amount of powdered datura leaves that they burn for each inhalation, until it becomes an abuse; and when at last they find that they are deriving but slight relief from the drug, they also find that they are unable to abandon it. They have become 'stramonium slaves'!

COCAIN AND THEIN

Some asthma-powders contain tea; but the use of the leaves of coca and tea in the form of cigarettes is only a mode of chronic intoxication; cocain or thein is not employed in this manner medicinally.

TOBACCO

Tobacco is now rarely employed therapeutically; but notwithstanding the seemingly irrefutable arguments advanced against its habitual use, its consumption as a luxury steadily increases. While the presence of nicotin in the smoke of tobacco has been denied (Vohl, Eulenburg), it is universally agreed that there do exist a certain number of volatile bases having a similar effect—pyridin and its derivatives, picolin, lutidin, collidin, etc. There are also present ammonia, nitrogen, oxygen, carbon monoxid, various hydrocarbons, and sulphurous and hydrocyanic acids. An important influence is exerted by the manner in which the tobacco is consumed; in the cigar, combustion is complete, and the smoke contains collidin especially; in the pipe, combustion is not complete, and pyridin predominates.

Physiologic and Toxic Effects.—I shall not go into detail concerning the symptoms of acute or chronic poisoning with tobacco. It cannot be doubted, in spite of impassioned attacks upon its use, that tobacco in moderation produces a more agreeable humor and a quicker wit; renders bodily and intellectual labor more easy and increases one's resistance to fatigue. Another favorable effect of tobacco is upon digestion, caused by the increased flow of saliva and its action upon the intestine. We must admit that its good effects are largely counterbalanced by numerous troubles quite properly attributed to the abuse of tobacco, such as irritation of the mouth and pharynx, dyspeptic troubles ending in hypopepsia, vertigo, loss of memory, tremor, amblyopia, palpitation, myocarditis, and angina pectoris. I may remark here, however, that these toxic accidents are observed almost exclusively in those individuals who not only inhale but swallow the smoke, and among those who absorb to a greater or less extent the tobacco juice from pipes or from chewing upon their cigars. Never-

theless, it cannot be denied that habitual chewers of tobacco, who at present, it is true, are chiefly found among laborers and those who live chiefly in the open air, suffer less from the effects of the weed than smokers.

Inhalations of tobacco in cases of **spasm of the glottis** (Chapman), of **whooping-cough,** of **asthma** (Salter), and of **hysterical hiccup** have fallen into disuse.

HASHISH (INDIAN HEMP)

Hashish is a product composed essentially of the flowering tops of Indian hemp; but it includes, besides, other substances—opium, cantharides, etc. Millions of men, chiefly in the East, consume this drug, which, among them, takes the place of tobacco. It is often employed for smoking, and affords a fragrant odor.

It gives rise to hallucinations of a pleasurable nature, varying in different individuals; each has his visions according to his natural bent. We need but recall the enthusiastic descriptions of Théophile Gautier in his most polished style, in "Club des Hachischiens," descriptions which have been verified and reproduced by Schroff, H. C. Wood, Fronmüller, and Ch. Richet.

Medicinally, cannabis has been employed only internally, in the form of the extract or of the tincture, as a **hypnotic,** and as an **analgesic,** especially in certain **psychopathies** (Moreau de Tours, Clouston). While it is possible that in certain painful affections therapeutic application might be made of cannabis fumigation, with careful dilution of the active drug, as yet physicians have hesitated to advise it.

OPIUM

Opium-smoking is a passion in the extreme Orient, and in many American and European cities there exist clandestine opium dens, patronized by Orientals, or by individuals who are looking for new sensations, some of whom succumb to the habit.

Armand has tried to employ these fumes therapeutically. His apparatus consists of a pipe, the bowl of which, of a globular shape, is made of porous earthenware. In this bowl the extract of opium is burned, and the fumes are inhaled through a tube. In cases of **intense dyspnea** relief is promptly obtained (Gubler). The inhalation of three or four whiffs of this smoke, containing nearly all the alkaloids of opium, and particularly morphin (Reveil), suffices to produce a considerable effect. Ethmuller has employed opium inhalations for their **sedative effect upon the nervous system**; he uses cigars containing:

Extract of opium, ...	0.15 gram (¼ grain)
Belladonna, ...	3.0 grams (45 grains)

Inhalations of warm aqueous vapor impregnated with camphorated opium tincture are sedative in **acute laryngitis,** and sometimes in **pneumonia.** (See page 383.)

BALSAMICS

The use of balsams can be traced back to remote antiquity, and the sacred writings of most religions contain references to their curative and prophylactic virtues. Warmly recommended by Bennett in the seventeenth century, and even during the first half of the last century by Delpit, Martin-Solon, and others, the balsams to-day are too little employed. Among others, the following have been used: **benzoin, balsam of tolu, balsam of Peru, storax, styrax, balsam of copaiba, myrrh, chamomile, incense, galbanum, asafetida, gum ammoniac.** Nowadays, benzoin is almost the only remedy of this group administered by inhalation. Rozière has, however, recommended strongly the use of **ethereal solution of tolu,** 20 grams (five drams) of tolu to 60 grams (two ounces) of ether, in cases of **bronchial catarrh.**

Benzoin is employed after the method preferred by Trousseau, which consists in burning a few pieces on a hot shovel and charging the atmosphere with vapors which the patient inhales. It is to be noted that benzoin enters prominently into the make-up of many fumigating powders, cigarettes, lozenges, etc. Another method consists in adding the tincture, drop by drop, to hot water. These inhalations last from five to thirty minutes, and are repeated from two to four times a day. I am using constantly, with considerable success, the tincture of benzoin, with or without menthol, in the treatment of obstinate cases of **catarrhal laryngitis** (see page 384), and especially in **post-grippal bronchitis.** The **tracheitis** which is so often present at the beginning of an influenza frequently persists a long time after other symptoms have disappeared. It is a condition difficult to modify by treatment, and, owing to its painful, annoying symptoms, leads the patient to demand relief either at the hands of the general practitioner, who tells him there is nothing the matter with his chest, or at the hands of the laryngologist, who, should his attention not have been called to this point, declares that the patient's pharynx and larynx are normal. It is in just these cases that the tincture of benzoin is the best and surest remedy.

CHAPTER V

ATOMIZATION (PULVERIZATION — NEBULIZATION) OF LIQUIDS; INHALATION OF MINERAL WATERS AT THEIR SOURCE

Atomization.—General Historical Review. Apparatus. Physiologic Effects of Atomization. Penetration of Finely Divided Liquids into the Air-passages. Technic. Pharmacology. Therapeutic Effects of Atomization and Indications. Inhalation of Mineral Waters at their Source.—Humage. Effects of Humage. Indications for Humage. Special Features of Individual Resorts. The Copper Sulphate Waters of Saint Christau.

ATOMIZATION

The therapeutic process commonly known as **atomization** or **pulverization** (and perhaps better termed **nebulization**) of liquids, consists—strictly speaking—in the mechanical division of medicinal liquids and solutions into exceedingly fine particles, constituting a veritable cloud or mist (nebula) which is to be **inhaled** by the patient for effect upon any or all portions of the **respiratory tract,** and also, at times, for **constitutional** influence. The name has been extended, however, to the use of rather coarse **sprays,** produced by a similar mechanical process, and used chiefly for **cleansing** or **topical medication** of the upper air-passages.

General Historical Review

The use by inhalation of the vapors of mineral waters at their source has long been practised, but it is to be remembered that these vapors do not contain all the active principles of the waters vaporized; indeed, some authorities have not hesitated to declare that the mineral constituents of the special spring resorted to are of little consequence, and that the chief, if not the only, effect is due to the vapor of water (Bertrand, Patissier, Saladin, Simonin, Filhol). Nearly fifty years ago, the Society of Medical Hydrology of Paris undertook the study of the vapors of mineral waters, and their value from a clinical and therapeutic standpoint. This was the occasion for the able investigations of Sales-Girons, of Pierrefonds, whom it is but just to recognize

as the great promoter of the use of atomized liquids (or, as he termed the process, *pulvérisation des liquides médicamenteux*) in the treatment of diseases of the respiratory tract (1855). Schneider and Walz, who had previously employed atomization for its balneotherapeutic effect only, and Auphan (1849), who had his patients breathe in a room the walls of which were sprinkled with mineral water, were too primitive in their methods to deprive Sales-Girons of priority. With the ingenious apparatus to be described later, the air in certain portions of the inhalation apartment was filled with the atomized liquid (**spray, nebula**) and the patients entering the room respired the atmosphere thus charged.

The new method gave rise to heated discussion. It was asked whether there was any real advantage in replacing the method of inhalation of vapors by that of atomization; but there is no doubt that, as Sales-Girons demonstrated, the old method of inhalation utilized only the volatile substances contained in the mineral water employed, while atomization permits the solution with all its components to be introduced into the air-passages. Thénard, indeed, had recognized that saline matter did not evaporate, but that the liquid particles are projected in a fine stream carrying with them the saline substances. The atomization of a liquid divides it into numberless very fine particles, but they do not reach the molecular state (Gavarret).

It has been urged against atomization that—for example—a considerable part of the sulphur of the sulphureted springs is lost. The work of Reveil, Poggiale, Filhol, Bonjean, and François leaves no doubt on this point, which is especially appreciable in the waters containing free hydrogen sulphid, while the waters containing only sodium sulphid (waters of the Pyrenees) are but slightly modified. But that is surely no reason for preferring simple vaporization, which causes a still more decided diminution in the quantity of sulphur inhaled!

A series of experiments undertaken by Filhol demonstrates that atomization robs the air of oxygen. This loss of oxygen in rooms where the water is atomized should not cause anxiety, said Sales-Girons, because patients suffering from pulmonary diseases are beneficially influenced by a stay in the high altitudes of Mexico (2000 meters) and other rarefied atmospheres relatively poor in oxygen. While the argument is, however, scarcely incontestable, the clinical fact remains true.

Atomization, the 'powdering' of water, is attended with a considerable fall in its temperature—a fact not to be denied. Some advanced

this, too, as an argument against the new method, alleging that it produced chilling of patients suffering with bronchitis or chronic pulmonary affections. They therefore asked for its suppression. The degree of the cooling of the water—which was found to vary from one-seventh to one-fifth of the initial temperature when the process was resorted to in a room with a constant temperature (Chateau)—depends upon the diameter of the atomizer, and, according to Poggiale, on the barometric pressure, on the hygrometric state of the surrounding air, on the extent of the evaporating surface, on the renewal of the air, on the changes in the air compressed, and on other minor factors. Hence, it was sought to remedy this fall in temperature by raising the temperature of the place of inhalation (Demarquay and Tampier)—which allowed complete saturation—or by the aid of special apparatus, or of special precautions which we shall refer to in describing the methods of atomization. It may here be noted that, according to the experiments of Bourgoin, the previous heating of the liquids to be atomized has not the appreciable result that might be expected *à priori*.

From a therapeutic viewpoint, the most serious objection raised against the method of atomization was the assertion that atomized liquids **did not penetrate** into the air-passages. This objection it is worth while going into; it is, in fact, a question vital to this form of treatment (Beni-Barde). Sharp and protracted discussions arose at the Society of Hydrology and at the Academy of Medicine of Paris.

Pietra-Santa, after experiments upon animals and upon himself, concluded that atomized liquids do not penetrate into the bronchi and that they do not even reach the larynx. Fournié, who admitted that fine particles of dust are carried into the lungs by the inspired air, also, at first, denied after personal experiments, the like penetration of atomized liquids. Demarquay, Sales-Girons, Reveil, and Bourgoin undertook a series of experiments upon animals that gave positive results. The technic adopted was the following: A rabbit was held about 30 centimeters from the atomizer and its mouth kept open by means of a dilating forceps. To avoid error from the entrance into the air-passages of liquid condensed in its mouth, the animal was suspended by the hind legs. The spray of a 1 per cent. solution of ferric chlorid was directed into the mouth for about one minute; the animal was then allowed to breathe, and the atomization was thus repeated four or five times. The rabbit was then killed, and the larynx, trachea, and bronchi examined. On touching the mucosa of this tract with a solution of potassium ferrocyanid, a blue coloration resulted, proving undeniably the presence of the iron salt. The characteristic blue re-

action was also found in the lungs. The same reaction was obtained when the potassium salt was the atomizing fluid, and the iron solution was the testing agent (Demarquay).

Briau, at the College of France, verified the exactness of these tests; but in identical experiments on dogs, and in one experiment upon a horse, arrived at a contrary result. Briau was therefore in doubt about the penetration in man, thinking that the successful results in rabbits were due to the fact that in this animal the glottis is close to the opening of the mouth. In the dog the test did not succeed unless the tongue was fixed by a string in such a way as to draw it down and a little out (Bourgoin). Finally, it may be added that most animals so treated, if left to themselves, died within forty-eight hours of acute pleuropneumonia (Frouneau).

Demarquay had the opportunity of experimenting upon a woman who had a very large tracheal fistula after tracheotomy. After this opening had been hermetically closed, the patient was placed before the atomizer of Mathieu, containing a solution of tannin; at the end of several inspirations tests were made of the penetration of the solution; paper soaked in a solution of ferric chlorid turned black when introduced into the trachea; a similar result took place when the patient, instead of breathing in an atmosphere charged with atomized liquid, was submitted to immediate buccal atomization by directing a spray into the mouth from a distance of about 25 centimeters. Trousseau admitted that this experiment was absolutely conclusive, and published a series of clinical observations entirely favorable to the method.

The experiments were repeated many times in different ways, and numbers of laryngologists and physiologists verified the results upon their own persons (Fournié, Moura-Bourouillou, Henry, Gratiolet, Tobold, Schnitzler). After inhalations of atomized solutions of iron terchlorid, and then of potassium ferrocyanid, the vocal bands have been seen in the mirror to be stained blue. Zdekauer was able to demonstrate large quantities of ferric chlorid in the lungs of a patient who, a short time before death, had been submitted to atomizations of that drug. F. Fieber repeated successfully the experiments of Demarquay upon several tracheotomized subjects. Lewin, after experimenting with an animal, remarked that the opening of the mouth, the traction on the tongue, and the struggles of the animal changed the normal respiratory conditions. Like Zdekauer, he was able to demonstrate the presence of iron in the pulmonary cavities of a patient who had been submitted to ferric chlorid atomizations. A student

rise to hemoptysis. Pidoux and Durand-Fardel admitted, with reluctance, the entrance of such liquids into the bronchial ramifications, and considered atomization useful in disease of the retropharynx and larynx, but of no value in deeply seated lesions of the bronchi or lungs.

According to Bourgoin (1863), in order that penetration may occur it is necessary to open the mouth wide, to protrude the tongue somewhat, keeping it well on the floor of the mouth, and to breathe slowly and deeply, stretching the neck and tilting the head a little backward. The first attempts are always difficult, breathing is bad, and the penetration of the first portions of the liquid causes irritation of the mucosa, retarding respiration and provoking cough. Usually tolerance is rapidly acquired.

APPARATUS

Atomization may be performed in rooms especially constructed for this purpose, in which are situated powerful atomizers that charge the air with the medicinal nebulas. This process, employed at numerous watering-places, has entirely displaced the method practised at Enzet-Les Bains by Auphan, who since 1849 had obtained the atomization of liquids by projecting streams under great pressure against the walls of a room. The more common method of atomization is by the use of small, portable spray-producers and nebulizers, that project the atomized liquids into the patient's air-passages; or from which he inhales; or with which both procedures may be combined.

Atomizers may be grouped into three classes, depending upon the principle adopted:

I. Apparatus in Which Atomization is Effected by the Projection of Liquid under Pressure Against a Solid Surface

The **apparatus of Sales-Girons,** the earliest in use, is constructed upon this principle. This is how the author himself describes his installation at Pierrefonds: Imagine a suction- and force-pump with a force of five atmospheres, the lever of which is worked by hand. On the suction side the pump communicates by a tube 3 to 4 meters (10 to 12 feet) long with the water of a sulphur spring; on the other side it forces the water aspirated through the first tube into another tube which pierces the middle of the ceiling of the inhalation chamber. At the termination of the latter tube is the atomizing apparatus, and here the atomization of the mineral water takes place. The atomizer is a hollow end-piece, pierced by three or four capillary openings in

such a way that the water emerges in very fine streams, disposed so that at a distance of 6 to 7 centimeters (2 to 2½ inches) they strike each at a different angle, upon a little metallic disk, where the streams, already broken into drops, become atomized and are reduced to a fine cloud of vapor (nebula).

Later **Sales-Girons** saw the necessity for a portable apparatus and invented a model (Fig. 87) which to-day is merely a historic curiosity. It is composed of a hand-pump, sucking up the solution to be atomized and forcing it under pressure through a tube, from which it escapes in a capillary stream. This stream was directed either upon a metallic disk or upon a metal screen, where it became very finely divided. A cylinder permitted the operator to direct the nebula into the mouth of the patient.

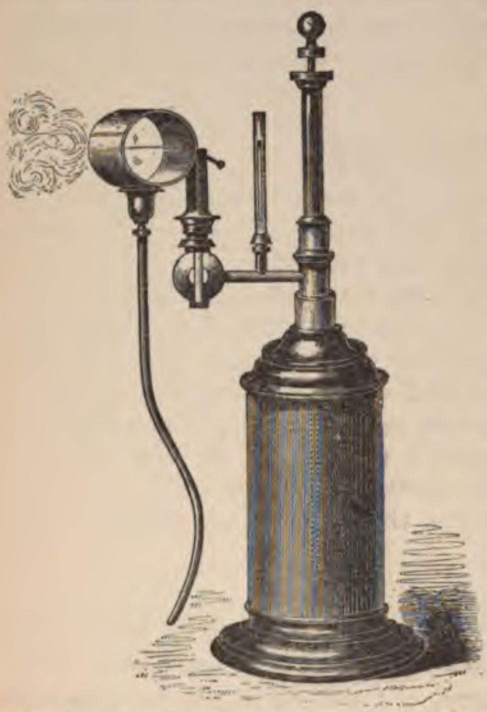

FIG. 87.—PULVÉRISATEUR PORTATIF OF SALES-GIRONS.

The apparatus had serious defects: (1) the pressure being too strong at times caused the apparatus to deteriorate; (2) the atomized liquid underwent a decided reduction in temperature. Charrière and Collin, later Laures and Mathieu, tried to remedy this defect, by adapting a manometer to the apparatus, and by previously heating over an alcohol lamp the liquid to be used. In other forms of apparatus, instead of exercising direct pressure upon the liquid, it was preferred to accomplish the result indirectly by compressing the air above the liquid to three or four atmospheres (Charrière).

Costly and cumbersome, these apparatus are to-day almost entirely abandoned except for another purpose (aqua puncture), and for this only rarely. The thread-like stream of water under pressure is also occasionally utilized as a local application for the treatment of certain neuralgias. (See under *douche filiforme*, volume IX, pages 87 and 88.)

We shall not describe the atomizers of Waldenburg, Luer, Fourniè, and Baumgärtner. The most practical and most frequently used apparatus are those of Mathieu and of Lewin.

Lewin's glass nebulizer, or **hydrokonion,** is extremely simple, being composed of a glass reservoir covered by a metal cap in which are three openings. The first serves for the introduction of the liquid and is closed by a screw-cap; the second is for the attachment of the force-pump to compress the air in the reservoir; while the third affords exit to a slender glass tube, the lower extremity of which dips into the liquid in the reservoir (Fig. 88). When pressure enough is obtained, the stream of fluid escapes under pressure and impinges on a convex metallic button secured to the interior of a glass or metal drum, into which it penetrates through an opening on the side facing the stream.

FIG. 88.—LEWIN'S GLASS NEBULIZER OR HYDROKONION.

In France, inhalation chambers are now often fitted up with 'pulverizers' or instruments on the Sales-Girons principle—some to diffuse the nebula through the room, some with terminals suited for the use of individual patients—to which compressed air from a common source furnishes the motive power. Medicinal solutions may be used or medication may be derived from receptacles of volatile agents through which the air or water passes on its way to the atomizing device. Attachments for heating the atomized solution when desired, are also provided. The accompanying illustrations (Figs. 89, 90, 91) scarcely call for detailed description.

Wassmuth's Inhalation Apparatus.—Inhalation chambers provided with this apparatus are found at Reichenhall, Ems, Baden-Baden, Münster am Stein, Kreuznach, Colberg, Meran, in the medical clinic at München, and in a number of other places. By means of a pump driven by any suitable motor, the medicated fluid or natural mineral water is driven under pressure through a pipe and gasometer and enters the apparatus, where it is converted into a spray and forced through a number of openings into a circular terminal portion through which it

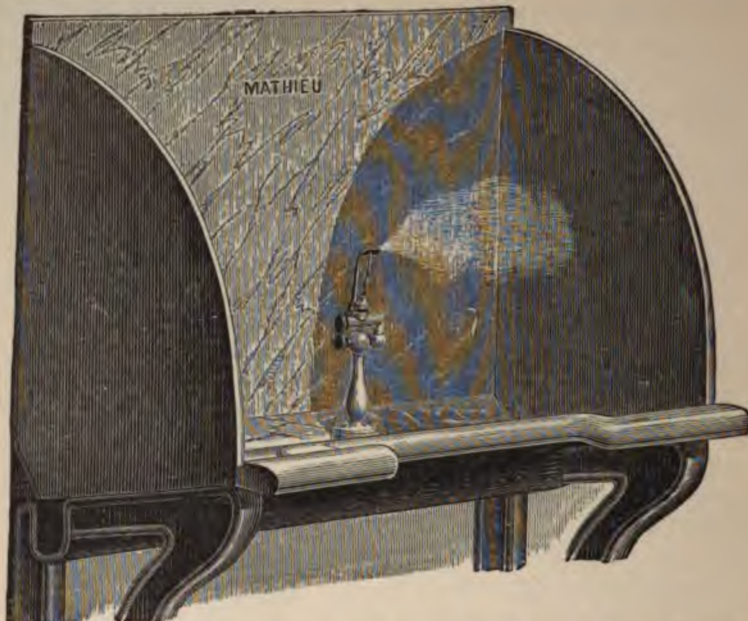

FIG. 89.—PULVERIZER FOR INDIVIDUAL USE MOUNTED ON MARBLE TABLE WITH MARBLE SIDE-PIECES AND CAST-IRON STAND AND GUTTER (DRAIN).

FIG. 90.—BRACKET-PULVERIZER WITH THREE NOZLES AND ABSORBENT COTTON RECEPTACLE, FOR INHALATION CHAMBERS.

escapes into the inhalation chamber. As the spray, before escaping, is driven against the sides of the bell it is chilled and becomes diffused

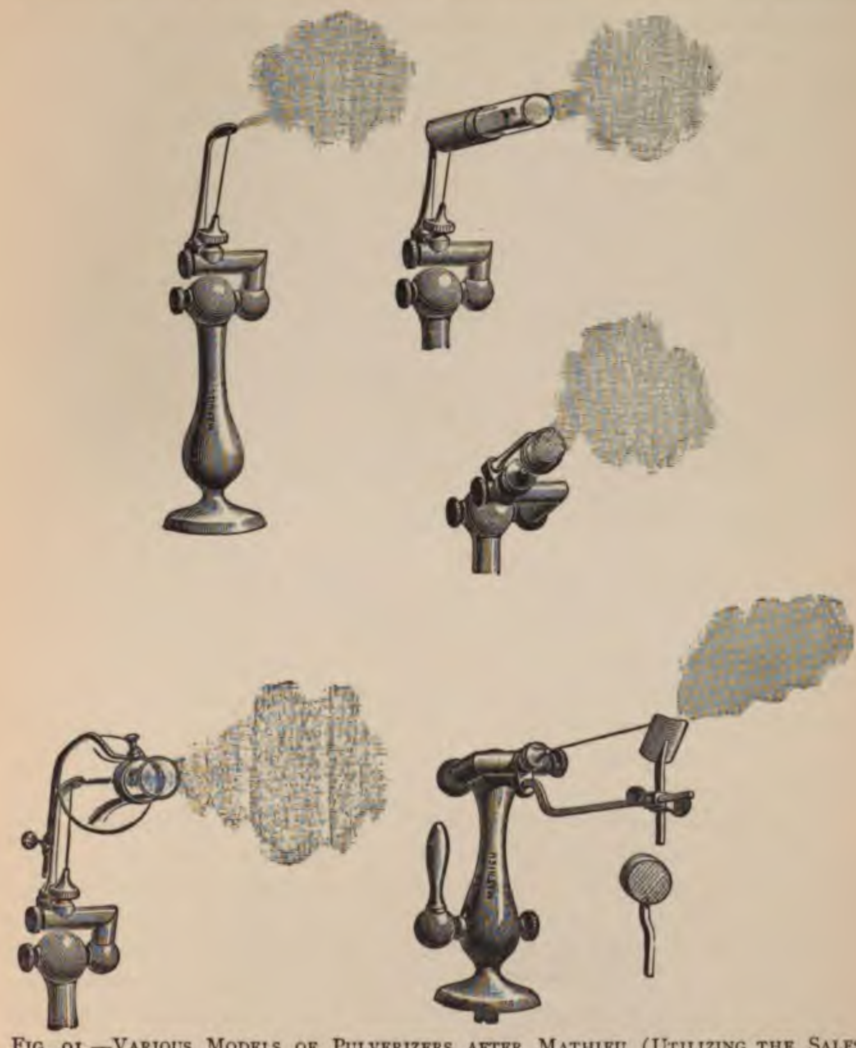

FIG. 91.—VARIOUS MODELS OF PULVERIZERS AFTER MATHIEU (UTILIZING THE SALES-GIRONS PRINCIPLE), WITH RECEPTACLES FOR MEDICATED ABSORBENT COTTON OR SPONGE, AND OPERATED BY MEANS OF A PRESSURE OF AT LEAST FIVE ATMOSPHERES.

in the room in the form of cold vapor. The atomization is accomplished by forcing two streams of water of a thickness of about 0.5 millimeter, under a pressure of 6 to 8 atmospheres, to meet at one

point at an acute angle, the particles being still further subdivided by repeated impact against the concave sides of the apparatus before they escape into the room. The entire room becomes filled with a vapor of extreme tenuity, comparable to a delicate mist; the hygrometer rises and registers 95 per cent. relative humidity, although no moisture is anywhere perceptible. The apparatus depends from the ceiling much like a hanging lamp. The ventilation with this system is excellent, the draft of the atomized fluid being utilized to draw in fresh air from outdoors. The current of air as it passes through the atomizer is freed from all its impurities before entering the room, while the vitiated air escapes through an opening near the floor. By this means about 900 cubic meters of fresh air are conveyed into the inhalation chamber in an hour. Only the finest particles of fluid pass through the bell into the room; the larger droplets are condensed within the apparatus and conveyed back to the receiver through an overflow pipe. The number of droplets not exceeding the size of a red blood-cell on one square centimeter of surface exposed have been counted by Gerlach, and found to vary between 45,000 and 130,000, after an exposure of about fifteen minutes.

II. Apparatus in which Atomization is Effected by the Simultaneous and Forcible Extrusion of Air and Liquid through a Small Opening

This type of apparatus was suggested by Tiermann and first constructed by Mathieu; hence it is known under the name of Tiermann-Mathieu. Instruments of the third class, to be described later, are constructed partially upon the same principle.

The Tiermann-Mathieu Nebulizer, or **Néphogène,** is composed of a metallic air-reservoir, surmounted by a force-pump for compressing the air in the reservoir. When sufficient pressure is obtained, a stop-cock is opened and the air rushes out through a narrow tube (Fig. 92), driving before it and with it a small quantity of the fluid to be nebulized, which is allowed to drip into the exit-tube from a glass globe above. An alcohol lamp placed near the extremity of the tube heats the spray as it escapes. This apparatus is rather expensive; there is no way of measuring the pressure; and, in addition, the spray produces a painful sensation in the mucous membrane, which very soon becomes intolerable.

FIG. 92.—TIERMANN-MATHIEU NÉPHOGÈNE.

FIG. 93.—SKETCH SHOWING THE PRINCIPLE OF THE BERGSON TUBES.

III. Apparatus in which the Liquid to be Nebulized is Aspirated and Forced Through a Small Opening (Bergson, Richardson, and Siegle Types)

In 1862 Bergson constructed, after a suggestion of Nathanson's, an atomizing apparatus consisting of two pointed tubes so joined at right angles that the extremity of the vertical tube stands in front of the axis of the horizontal tube (Fig. 93). A strong transverse current passing through the horizontal tube will rarefy the air in the upper portion of the vertical tube, and thus draw up any liquid in which the latter may be immersed. The liquid as it meets the

FIG. 94.—WADSWORTH'S OIL ATOMIZER.

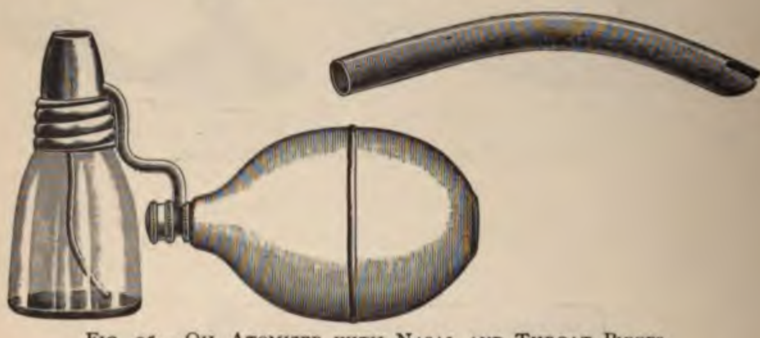

FIG. 95.—OIL ATOMIZER WITH NASAL AND THROAT PIECES.

current will be broken into a spray, the fineness and volume of which will depend on the size of the apertures of the tubes; but as the spray becomes finer, it necessarily diminishes in quantity. For oily solutions, so much used at the present day, rather coarse tubes are to be preferred; and a number of instruments of special types have been devised. (See Figs. 94, 95 and 96.) In apparatus of this class aspiration is effected either by (a) **air under pressure,** or (b) **steam under pressure.**

(A) Instruments in which Aspiration is Effected by Means of Compressed Air (or Other Gas)

In Bergson's original apparatus the **compressed air** was furnished

by means of a rubber foot-bellows of pear-shape, communicating with a globular rubber bulb covered with silk netting; the latter acted as a reservoir from which the current passed through rubber tubing to the horizontal tube of the atomizer. Andrew Clarke modified this by substituting the familiar rubber hand-bulb. The advantage of a double bulb is that it furnishes a continuous current with less pumping; the advantage of a single bulb, on the contrary, lies in the fact that the operation may be suspended abruptly at any moment. Accordingly, the purpose for which atomization is undertaken will govern the choice; for inhalation proper, the former—for douching, the

LENTZ & SONS

FIG. 96.—OIL ATOMIZER FOR CARRIAGE IN POCKET.

FIG. 97.—STEVENS'S FOOT-PUMP AND NEBULIZER.

latter, being preferable in most cases. At the present day, hand-bulbs are employed chiefly in instruments to be used by the patient at home (see Fig. 101); while in the physician's office, following the suggestion of J. Solis-Cohen, the sprays are usually driven by air drawn from a reservoir in which it may be compressed by a force-pump, or by one of the many ingenious devices that utilize the city's water-pressure. Compressed oxygen and compressed carbon dioxid (J. Solis-Cohen and James Collins) have also been employed. A satisfactory form of **cut-off** is necessary in these methods. Recently little foot-pumps, like those used for inflating bicycle tires, have been adapted by manufac-

turers to supply compressed air for the production of sprays and nebulas, and are quite satisfactory for domestic use (Fig. 97).

Bergson's **tubes** have been modified variously. Thus, Wintrich has bent the aspirating tube, prolonging it beneath and parallel with the air-tube, for a certain distance, producing a duck-bill effect. With

FIG. 98.—DE VILBISS'S ROTARY SPRAY TUBES.

an instrument of this kind the atomization can be effected within the patient's oral cavity, and the operator is enabled to make his applications with greater nicety. Still further modifications by Sass, by J. Solis-Cohen, and others, permit the spray to be **directed** as desired—upward, downward, forward, laterally, circularly—by bending the tip

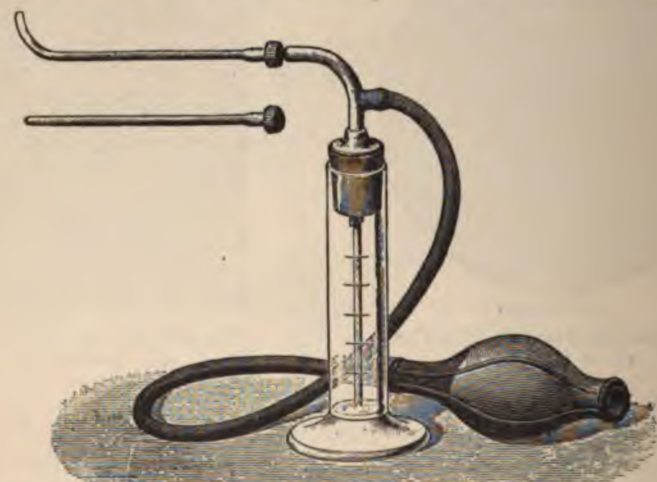

FIG. 99.—RICHARDSON SPRAY-PRODUCER WITH INTERCHANGEABLE TUBES FOR HOME OR OFFICE USE.

of the air-tube, or by utilizing multiple perforations, or by constructing the tubes of metal, with a rotary arrangement (Fig. 98). Sass introduced a receptacle like a test-tube which can be grasped in the hand of the operator, and thus greatly facilitates manipulation.

B. W. Richardson devised a spray tube for local freezing by rhigo-

lene and ether, which was soon adapted to respiratory medication and has almost entirely superseded the Bergson tubes in the atomizers now manufactured by the thousand for domestic use, as nasal and throat sprays. In this apparatus the Tiermann-Mathieu and Bergson-Wintrich principles are combined—the aspirating tube, after it emerges from the liquid, running within the air-tube. These instruments (Figs. 99, 100, 101) are sometimes made with flexible tubes, or have a number of interchangeable tips of various shapes,—straight, curved, bulbous, and the like,—to facilitate direct application to the nose, larynx, roof of

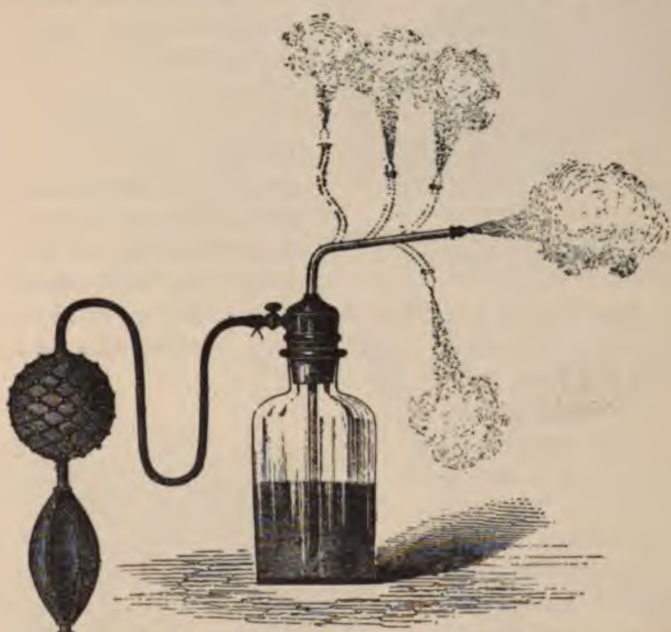

FIG. 100.—RICHARDSON'S APPARATUS FOR LOCAL ANESTHESIA.

the pharynx, etc. The forms of such devices are sufficiently obvious, and the accompanying illustrations will serve in lieu of description.

Apparatus constructed on the Bergson or Richardson principle are convenient for douches or for cleansing or topically medicating **sprays,** and are thus used daily. Their **disadvantages** for purposes of medicinal **inhalation** are: (1) The fatigue necessarily resulting from constant manipulation by hand or foot. The remedy for this defect, as stated, has been sought in the use of compressed air, liquid carbonic acid, or compressed oxygen, but this necessarily complicates the apparatus considerably. (2) The quantity of atomized fluid in the stream pro-

duced is very much less than that from the apparatus of Sales-Girons, and will not remain long suspended in the air. To improve this, it has been suggested that the solution be stored in a receptacle situated above the tube which carries the compressed air; in this way the pressure of the liquid is added to the aspiration produced by the current of air (J. Solis-Cohen, 1865). For the same purpose, Mans uses a third tube, communicating with the horizontal air-tube and passing vertically behind the tube dipping into the fluid, for the depth of a cork in which both are placed. In this way a direct pressure is exerted upon the surface of the liquid, forcing it up the perpendicular atomizing tube, and the power that would otherwise be consumed in aspiration is liberated for spray-production. (3) The spray is often too cold for inhalation. This has been overcome in Waldenburg's instrument, by keeping a spirit-lamp beneath the receptacle of fluid. The principal disadvantage, that of the insufficient volume and suspension of spray, was ingeniously overcome by Oliver, of Boston (1865), who combined the principle of Bergson with the principle of Sales-Girons. The spray from a Bergson or Richardson tube was made to impinge on the side of a glass globe, whence it escaped, through another opening, in a dense cloud of very fine particles remaining in suspension for an appreciable time. This has later been modified by Oliver and

FIG. 101.—COMMON FORM OF RICHARDSON ATOMIZER FOR DOMESTIC USE.

FIG. 102.—STEVENS'S HAND-BULB NEBULIZER WITH VARIOUS ATTACHMENTS.

others into the small and easily manageable type of instrument shown in the illustrations (Figs. 97, 102, 103, 104, and 105), and to which, in America, the name of '**nebulizer**' has become specially attached. Compressed air from a foot-pump, hand-bulb, or reservoir produces with Bergson or Richardson tubes of special design a spray within a small glass receptacle of any convenient shape; this spray is broken up on the side of the container and escapes through a special tube fitted with mask, mouthpiece or nasal olive. If, as advised by Evans (1887), a little glycerin be added to the fluid to be nebulized, suspension is almost indefinitely prolonged. To warm the inhaled nebula, the receptacle may be placed on a water-bath. 'Multinebulizers' (Fig. 103), much employed in the United States, are combinations of nebulizers, convenient and

FIG. 103.—STEVENS'S MULTINEBULIZER WITH INHALING MASK.

FIG. 104.—OLIVER'S NEBULIZER.

FIG. 105.—STEVENS'S NEBULIZER WITH NASAL OLIVE TERMINAL.

suitable for the physician's office, and usually operated with condensed air from a reservoir.

(B) Apparatus in which Aspiration is Effected by Means of Steam (Siegle Type)

To overcome the disadvantages of the instruments using compressed air, Siegle proposed to utilize the Bergson tubes with steam as the driving

FIG. 106.—SIEGLE'S INHALER.

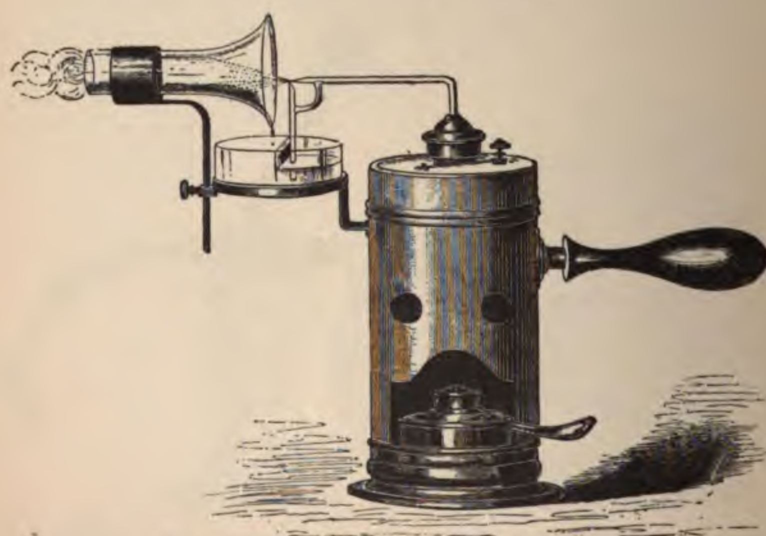

FIG. 107.—OERTEL'S NEBULIZER WITH SHIELD.

power. In his original **steam nebulizer** (Fig. 106) the medicated solution itself, heated directly over a spirit-lamp, furnished the steam for aspir-

ation and pulverization. In the later instruments of Siegle, of Lister, of Lucas-Championniere, of Oertel, of Reverdin, of J. Solis-Cohen, and others, plain water is heated and furnishes the column of steam that aspirates and atomizes the medicinal solution; the latter being contained in a vessel attached in some convenient way to the boiler in which the steam is generated, and from which it issues along the horizontal tube of Bergson's pair. At the upper part of the boiler is placed a safety-

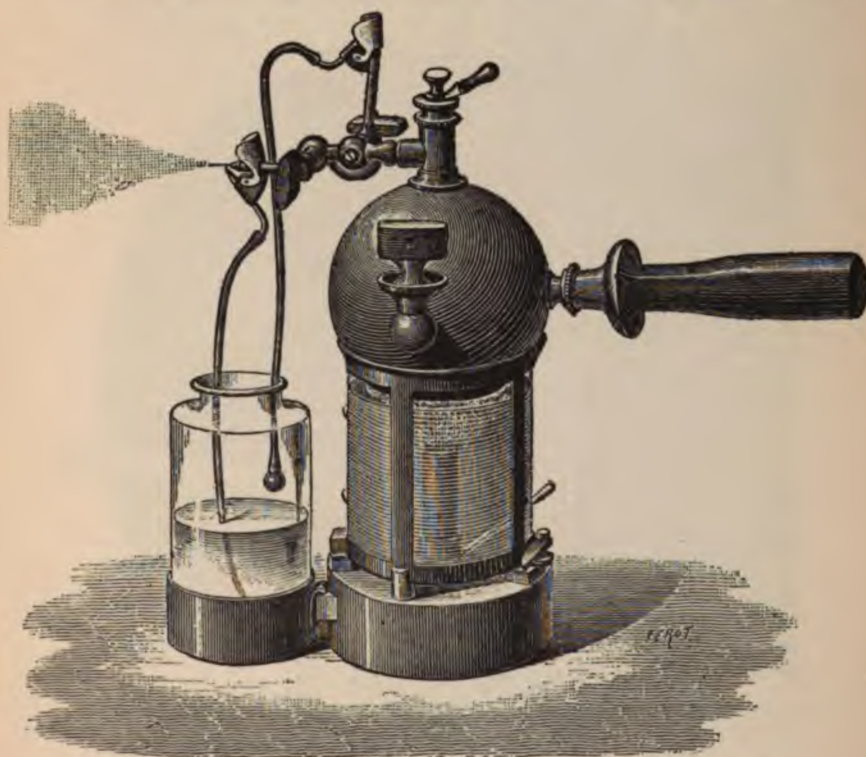

FIG. 108.—MATHIEU'S MULTIPLE STEAM ATOMIZER FOR HOSPITAL USE.

valve for the purpose of preventing an explosion, always possible because of the small size of the tube, and its liability to become plugged. Little has been accomplished—or was needed—in the way of perfecting the apparatus of Siegle. Indeed, many of the changes proposed have complicated it considerably—*e. g.*, the instrument of Jahr, which is designed to raise the temperature of the medicinal spray. The accompanying illustrations (Figs. 107 to 112) will indicate sufficiently the

nature and variety of these devices, some of which are intended to permit of inhalation by a number of patients at one time, others to protect the patient's face, others to vary the direction and volume of the spray, or the manner of medication, etc.

The **advantages** of apparatus in which steam is the motive power are the simplicity of the mechanism, the moderate cost, the possibility of maintaining the medicated vapor at a fairly high temperature, and of graduating the strength and amount of the solution at will.

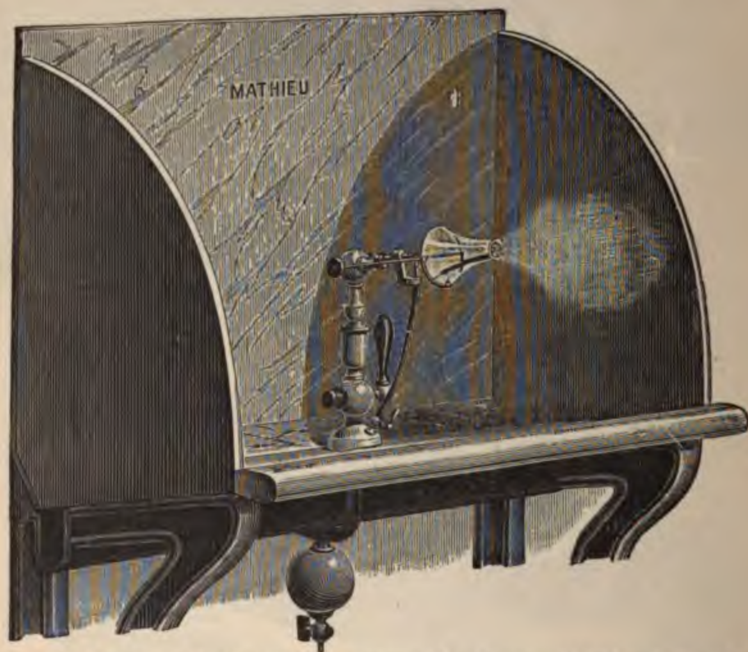

FIG. 109.—APPARATUS FOR HOT PULVERIZATION, OPERATED BY STEAM, WITH CONDENSING GLOBE AND SELF-CLEANSING STOPCOCK, MOUNTED ON MARBLE TABLE.

One must not forget the admixture of steam, and must avoid deleterious effect on the buccal mucous membrane, such as we have referred to in connection with apparatus for the direct inhalation of the vapor of water.

REFLEX EFFECTS OF ATOMIZATION

The inspiratory air-current under normal conditions enters the nose at first in a direction perpendicular to the plane of the nostrils, which is horizontal when the individual is in the erect posture. Under the

FIG. 110.—STEAM ATOMIZER WITH SHIELD.

FIG. 111.—COLLIN'S MULTIPLE STEAM ATOMIZER.

influence of aspiration, and because of the structure of the bony vault of the nose, the current is then deflected backward and downward, describing along the septum a curve ending at the posterior nares (Paulson), most often between the inferior surface of the posterior extremity

FIG. 112.—STEAM ATOMIZER WITH MULTIPLE ADJUSTABLE TERMINALS.

of the middle turbinal and the inferior surface of the posterior extremity of the inferior turbinal—the latter being almost in contact with the lower border of the posterior choana (Bloch). Thus the air-current passes by way of the inferior and middle meatuses, skirting along the septum. It might easily be taken for granted that by the inhalation of gas or

vapor, or by the method of atomization, substances capable of exerting a curative effect upon the mucous membrane of the nose would be brought into contact wlth these parts. That, however, would ignore the physiologic rôle of the nose, which has been well described as the 'sentinel of the air-passages.' It allows the atmospheric air to pass for purposes of respiration, without challenge, but the case is quite different when the air is charged with gas, vapor, or liquid or solid particles. The '*vibrissæ*' that occupy the nasal entrance represent a filter,—coarse, to be sure; a large-meshed network,—but capable of impeding the further progress of a large number of solid particles, of fixing liquid globules, and of condensing certain vapors. Assuming this filter of cilia removed, we should still have to deal with the **sensibility** of the nasal mucous membrane, and this sensibility is of two kinds, general and special.

The **nerves of general sensation,** supplied by the trigeminus, react sharply to substances of an irritating nature, volatile or otherwise. This reaction is accomplished by three distinct phenomena, all three serving the same purpose: namely, the expulsion of the irritating agent. The first phenomenon is psychic, consisting in the perception of the more or less disagreeable excitation of the mucous membrane—the recognition of abnormal substances in the inspired air. The second stage in the reaction is vasomotor and secretory: the circulation in the mucous membrane becomes more active, as does also the glandular activity—the stimulation resulting in the secretion of a variable amount of thin mucus which engulfs the solid particles or absorbs the volatile ones; if the irritation be still greater, the secretion becomes profuse, serous, transparent, and alkaline in reaction, stimulating the movements of the cilia; at the same time, the membrane becomes tumefied and the access of impure air is rendered more difficult. The psychic warning and the hypersecretion necessitate a voluntary expulsive action, calling forth the blowing of one's nose. The third phenomenon, involuntary in nature, is reflex, and gives rise to sneezing; that is, a short, violent expiration.

The nose is also the seat of the **special sense of smell,** which also apparently guards the purity of the inspired air; the larger number of substances that might vitiate it, being odoriferous, are naturally under the observation of that sense.

Moreover, we must bear in mind the anatomy of the uneven nasal fossæ, dominated by the osseous structure, effecting mechanically a slowing and distribution of the air-current, and thus allowing the more complete arrest and precipitation of impurities.

These considerations teach us that all substances, gaseous, vaporized, atomized, or powdered, used in the air-passages must, so far as possible,

be deprived of their irritant properties. Atomized solutions, in particular, must be very dilute and lukewarm, avoiding all mechanical irritation like that of a stream directed immediately upon the mucous membrane; in addition, one should select non-irritating substances, and so far as possible solutions should be approximately isotonic with the blood-serum. The so-called physiologic sodium chlorid solution (0.77 per cent., 7.7 grams to the liter—say 60 grains to the pint) constitutes perhaps the best fluid for atomizing purposes, and is used by me in preference to any other, either pure or as a vehicle.

PENETRATION OF FINELY DIVIDED LIQUIDS INTO THE AIR-PASSAGES

Frequent experiments have been undertaken to demonstrate the possibility of fine particles of dust and, *á fortiori*, of atomized liquids, passing through the **nasal fossæ.** These observations can be neither valid nor convincing unless the artificial conditions closely simulate those which obtain physiologically (Aschenbrandt). The penetration of gases and vapors into the nasal fossæ needs no demonstration; that of fluids does. For this purpose I have made use of agents demonstrable by color reactions. The following are the results of my experimentation:

The Nasal Chambers.—In **atomization** resorted to by patients themselves with an apparatus supplied with an intranasal tip, the solution reaches only the anterior extremity of the inferior turbinal and the anterior part of the septum; 3 times out of 20, the anterior extremity of the middle turbinal. The floor of the nasal fossæ and the inferior meatus show the reaction, but that is the result, pure and simple, of condensation and deposition of the liquids. When the patients are placed at a distance of 20 to 40 centimeters (8 to 16 inches) from the atomizer, providing no abnormality, congenital or acquired, be present to prevent penetration, the fluid, after a sitting of ten to twenty minutes, will have reached the greater part of the inferior meatus, the inferior turbinal, the septum and the anterior third (occasionally more) of the middle meatus and middle turbinal. When **solid particles** are insufflated, they become fixed on the anterior portion of the septum and of the inferior turbinal, and do not penetrate deeply, becoming surrounded by the secretions they excite. Occasionally among inveterate snuff-takers, thanks to a tolerance acquired by the mucous membrane, the diffusion is wider.

What has been said about atomized liquids and powders does not, however, apply under certain **pathologic conditions,** particularly, **ozena.**

In this disease the lessened sensibility and the abnormal width of the nasal fossæ, resulting from atrophy of the mucous membrane and of the bones, allow of very different results. The solution in almost every instance reaches the entire surface of the nasal chambers.

The Oral Cavity.—The mouth (and buccal surface) throughout its entire extent allows easy access of substances used by **inhalation, atomization** or **insufflation.**

The Pharynx (Oral).—The same possibility exists here as with the mouth; but we must always bear in mind certain restrictions in the use of **atomized solutions.** Many patients,—perhaps more than half,—while employing atomization, instinctively breathe through the nose. As a result the fluid does not pass beyond the anterior palatine folds. Therefore it is necessary, if one desire to obtain results, to advise patients not to use a tip which is introduced into the mouth, but to place the apparatus at a distance of at least 20 centimeters (8 inches), and to breathe constantly through the mouth; or, at least—to follow the direction usually given to patients suffering from diseases of the tonsils and pharynx—to breathe through the mouth once out of every three inspirations. Nasal breathing may be permitted, however, provided the tongue be drawn out over the lower lip. Some patients, to avoid fatigue, prefer to hold the tongue drawn out of the mouth, in a fold of gauze or linen between the fingers.

The Nasopharynx.—Pure **atomization** is rarely practised in this region, and apparatus designed for this especial purpose are used only exceptionally; nevertheless, I have seen good results from the method in obstinate diseases of the pharyngeal vault, especially in **dry catarrh** and **painful lesions.** The use of so-called post-nasal sprays as **douches,** and even for **topical medication,** by means of suitably curved Sass tubes, or of Richardson tubes with a special tip, is, however, very common.

The Larynx.—From its situation, the epiglottis offers considerable opposition to the entrance of atomized liquids into the larynx. It does not offer absolute obstruction, even if one do not try to defeat its apparent chief physiologic purpose (Guinier's experiments to the contrary, notwithstanding): namely, to protect the air-passages from the entrance of foreign bodies. Besides the opposition afforded by the sensibility of the buccal surface of the epiglottis—the resultant reflex from irritation of which is either a sense of nausea, or the motion of swallowing, which closes the larynx—there should be noted, and perhaps accorded chief attention, the obstruction to the passage of the spray from the atomizer, resulting from a more or less oblique position of the epiglottis over

the entrance to the larynx. In the usual position, the mouth being open, the spray cannot enter the larynx directly; that which does enter being only a small part of the fluid which is reflected from the posterior pharyngeal wall, like the light rays from the mirror during a laryngoscopic examination. The problem therefore resolves itself into avoiding excitation of the reflexes in this peculiarly sensitive locality, and the desirability of direct application of the atomized liquid, gas, or vapor to the cavity of the larynx. To accomplish the latter purpose, it has been recommended to diminish and, so far as possible, to suppress the obstruction offered by the epiglottis. It is sufficient to use a tongue-depressor, one long enough to depress firmly the base of the tongue, in order to draw forward the epiglottis at the same time. Kirstein has devised an instrument specially curved and admirably adapted to the end in view. In this way it is possible to get a direct view of the interior of the larynx and consequently the desired medication may be applied directly. This procedure, it is true, is far from easy in practice and has not been adopted as a routine. For many years, however, I have succeeded in carrying it out with patients who have recognized by experience that it is the best means of practising inhalation.

In the more general method, patients are first instructed to project the tongue as far as possible. It is then grasped with a cloth held in the fingers, preferably beween the thumb and forefinger of the patient's right hand, and pulled downward as far as possible. Lazarus recommends that the organ be rolled, as it were, around the lower lip. In this way is prevented the arching of the base of the tongue that often causes a narrowing of the ostium of the pharynx, while the lingual traction causes the epiglottis to be lifted up and well forward. The patient throws his head slightly forward, at the same time tilting it a trifle backward and upward, bringing his lower jaw as far forward as possible. These manœuvres have for their object the greatest possible widening out of the angle between the axes of the buccal and laryngeal cavities. In this position the medication may be made to reach the vestibule of the larynx, even in the most difficult cases.* The mucous membrane of the larynx is of an extremely sensitive nature; the entrance of any mixture other than

* Under guidance with the laryngoscopic mirror, at the same time directing the patient's respiratory efforts or calling upon him to make certain sounds, an expert manipulator can, with a suitably curved tube, easily throw a spray to any portion of the larynx or into the trachea. The long sound "Ah", or in certain patients the vowel "E" (French *i*) given in a rather high pitch, lifts the epiglottis and brings the vocal bands into view and access. If this be followed by a deep inspiration the subglottic structures will be exposed for a sufficient time. Simple coughing is advised by Pynchon.

the atmosphere brings into play the various reflexes acting on the secretory, vasomotor, and muscular apparatus of the organ, and on the group of expiratory muscles; the latter reflex provokes cough. In inhalation through the mouth, in addition to the obstacles offered by the mouth itself (increased secretion), by the pharynx and the base of the tongue (narrowing of the orifice, effort at deglutition), of the epiglottis (obstruction to the laryngeal entrance), and of the sensitiveness of the mucous membranes of these parts, especial note must be made of this peculiar irritability of the larynx, trachea, and bronchi, showing itself by cough, and by spasmodic closure of the glottis. More especially it is this closing of the glottis that constitutes the chief obstacle to the penetration of inhaled substances into the air-passages; this may result from various causes: from their quality, from their quantity, from their temperature, from their sudden introduction, and other irritant conditions. The spasm depends mainly on the sensibility of the mucous membrane, which varies in different individuals. This fact explains the apparently contradictory results obtained by different experimenters. Those who assert that inhaled medicaments pass the larynx and reach the trachea and bronchi have had subjects with very tolerant air-passages. This was undoubtedly the fact in the case cited by Waldenburg: the patient had a paralysis of the muscles of the pharynx; the larynx was normal; during the act of drinking the epiglottis remained upright and the fluid came into contact with the vocal bands, a fact that Waldenburg could demonstrate laryngoscopically. But the great sensibility of the larynx, that is to say, its specific irritability in the presence of foreign substances, cannot be doubted by any one who has practised endolaryngeal manipulations; on the other hand, laryngologists know perfectly how to overcome this laryngeal irritability; a short experience suffices, provided one proceeds dexterously and grades carefully the strength of solutions and mixtures and the length of sittings.

The Trachea, the Bronchi, and the Lungs.—We have now arrived at the trachea and bronchi. Here there are more mechanical obstacles; nevertheless, with dextrous manipulation they can be, and daily are, overcome. It would appear that medicated solutions after succeeding in passing these tubes ought to reach diseased parts of the lung; but as a matter of fact there are still other and greater difficulties.

First, there is to be remembered the sensitiveness of the bronchial mucous membrane, which reacts by swelling, by increased secretion, and by cough. Second, the medicinal substances, particularly atomized particles, tend to be precipitated, so that only the air penetrates to the alveoli. Finally,—and here we touch upon the strongest argument

against treatment by inhalation,—the diseased portions of the parenchyma are precisely those receiving the least amount of medication; for the air reaches the alveoli by aspiration, the inspiratory movement producing a negative pressure in the air-vesicles. Respiration is least active, and in fact often abolished, in diseased tissue; hence the inhaled drug in very many cases acts only or chiefly on the healthy portions of the lung, where its effect is at best negative, and may be positively harmful.

It follows from the last statement that only that portion of the medicament which is retained in the residual air becomes therapeutically effective; hence the fundamental law, accepted by most clinicians after careful analysis of their results, to employ only weak solutions, at frequent intervals, and to prolong the individual sittings.

Technic

As ordinarily practised, then, only a small quantity of the fluid atomized penetrates the air-passages during inhalation. Experiments by Beigel and Collin allow a positive conclusion; J. Solis-Cohen places the figure at from one-twelfth to one-sixth. Schreiber, reverting to a suggestion of Piorry's, attempted to overcome the difficulty by immobilizing the healthy portion of the chest in order to augment the action of the diseased part. (See also page 279.) I merely call attention to this method, which *à priori* appears rational, but I have no figures from which to estimate its efficacy; and personally I believe that if we instruct our patients to constrict the lower part of the chest as much as possible with a belt or a band of flannel, we cannot tell exactly which part will be most affected. The method, however, merits further study.

For **laryngeal,** and more especially for **bronchial** or **pulmonary applications,** it is absolutely essential that the patient assume the **position** we have indicated: mouth wide open, tongue well out with the tip strongly depressed, and the lower jaw drawn forward. This forward movement must be accompanied by a slight tilting of the head upward and backward. The patient breathes quietly and sometimes, following the suggestion of Moura-Bourouillou, the nostrils are plugged in order to insure mouth-breathing only. The sittings should not take place just after any vigorous exercise, and we should always wait (Siegle) until the temperature of the skin has resumed its normal state and the pulse its ordinary rhythm. Treatment must also be avoided directly after a meal, and during periods of excitement. During the inhalation the patients must refrain from talking; afterward it is a good plan to order them to rest. During the session the patient is comfortably seated about 15 to 20

centimeters (6 to 8 inches) or more, from the tip of the atomizer. Only robust subjects, namely those in whom we desire respiratory gymnastics, should be permitted to stand while inhaling; patients who are enfeebled, or whose temperature is much above normal (from hemoptysis, pneumonia, pulmonary gangrene, diphtheria, etc.) should be treated in the recumbent position, with the head suitably elevated.

The **temperature of the solution** used should be about the same as that of the parts to be treated. If the spray be too hot, it may irritate or even scald the mucous membrane of the mouth, pharynx, and larynx—besides, there results a condensation of liquids in the mouth, giving rise to involuntary movements of swallowing. If it be too cold, it will excite the terminal nerve-fibers, producing a disagreeable sensation, and often irritable cough. At the present time the use of ice-cold sprays for cases of hemoptysis has been abandoned. The temperature of atomized fluids, about 10 to 15 centimeters (4 to 6 inches) from the tip of the instrument, should be from 25° to 30° C. (77° to 86° F.).

The **duration of the sitting** is important. It is necessary to take into consideration the fatigue caused by the peculiar position of the patient and of his tongue, the attempts at deglutition caused by the condensation of the liquid in the mouth, and the increased secretion of saliva. At the beginning, the sessions should be short, lasting a few minutes only; after tolerance has been established the duration is gradually increased to twenty or thirty minutes. Longer sittings are rarely useful and occasionally do harm. When atomization is practised with a succession of patients in the same room, it is necessary to ventilate freely after each séance. One application a day generally suffices; in most cases, no more than two are employed. In certain instances these rules undergo modifications; thus, in **diphtheria** the inhalations should be more frequent and the duration of each period should be prolonged.

The **quantity of fluid** employed varies with its strength and the purpose of the application. **Dosage** is usually a matter of **time** and **percentage;** but occasionally the length of the sitting is regulated by the quantity of fluid atomized. During a typical application, lasting twenty minutes, about 30 to 50 grams (one to two fluidounces) of solution will be atomized with the ordinary instruments.

For the **nasal mucous membrane** the specially curved tubes that have been mentioned are usually employed with the idea that thus the stream may be directed to the immediate area involved. True, it is possible for the physician, if he uses an instrument that does not obstruct his view, to see exactly where and how to direct his medication; but it is quite different when one makes the application for himself. When we

consider the irregular configuration of the nasal cavities, it is easy to understand why the patient has no guide whatever, and by using colored fluids I have often verified the fact that the most intelligent persons fail to reach the desired spot. Most often the stream is directed against the septum or the anterior portion of the inferior turbinal. The effect produced is similar to, and often less effectual than, that of the douche. Consequently I have abandoned entirely the use of the atomizer intranasally by the patient himself, with one important exception—namely, when the lesions are situated at the orifice of the nose or in the vestibule. In certain erosions of the anterior portions of the septum and especially in **folliculitis of the vestibule,**—a condition often the despair of physician as well as patient,—this method of atomized applications is a decided, and often indispensable, aid, yielding results impossible with other means. In general, in affections of the nasal mucous membrane (**acute, subacute, atrophic, and vasomotor rhinitis**) I employ atomization practised in the same manner as in diseases of the laryngo-bronchial tract. The patient seats himself at a distance of not less than 15—sometimes 25, 30, and even 40—centimeters (6, 10, 12, 16 inches) from the apparatus, and breathes naturally through the nose.

PHARMACOLOGY

Before discussing the **indications** for the various remedies employed in this method, let us recall that the choice is restricted to **well-diluted solutions** of substances that may be **tolerated** for a long time without causing irritation of healthy tissues and without giving rise to distant lesions or systemic **poisoning,**—such, for example, as follows the use of strong carbolic acid sprays. Breathing should be more vigorous, more forced, the deeper the lesions are located.

It would be difficult to enumerate all the **substances** that have been recommended for use in atomization, and I shall not make the attempt; contenting myself with the mention of necessary types, and agents of proved utility. They have been **divided** into astringents, emollients, excitants, resolvents, sedatives, disinfectants, and anesthetics (Knauthe). This classification is convenient, but is scarcely defensible from a pharmacologic standpoint.

I believe the following to be more logical, without pretending that it is based upon pharmacologic laws: (1) **Astringents and hemostatics**; (2) **sedatives and anesthetics**; (3) **antiseptics.** I shall go over a rather long list, but without pretending that it is complete; and shall lay

special stress upon certain agents, most frequently used, or having special indications.

ASTRINGENTS AND HEMOSTATICS

Alum

This remedy has been employed in solutions of from 0.25 to 2 per cent. and even stronger, in **catarrhal affections** of the **palate, tonsils, pharynx** and **larynx** (Waldenburg, Schnitzler, Lewin). Schnitzler has recommended its use in **chronic laryngitis.** It has also been advised in **whooping-cough** (Siegle) in **chronic bronchitis** (DaCosta), in **pulmonary gangrene** (Trousseau), and various other conditions. It has been strongly recommended in cases of **hemoptysis,** especially those following a febrile exacerbation (Tobold, Siegle).

In a general way, the **indications** for alum are, like those of tannin, presently to be mentioned, tumefaction of the mucous membrane with congested blood-vessels and abundant secretions.

Tannic Acid

Tannin in the same strengths as alum has been advised in **granular pharyngitis** (Demarquay), **laryngeal tuberculosis, croup, edema of the larynx** (Trousseau), and **pulmonary gangrene.**

Ferric Chlorid

Iron terchlorid in 0.5 to 2 per cent. solution has been especially recommended in **hemoptysis** (Hillairet, Zdekauer, Lewin, Waldenburg, Siegle, DaCosta).

For hemorrhage from the mouth, tonsils or pharynx, the iron chlorid gives good results, so far as stopping the bleeding goes; but when the blood comes from the bronchioles of the lung itself, some authorities consider its use far from commendable. The opponents of hemostatic atomizations assert that absolute rest of the bleeding part favors coagulation much more than the use of solutions which may not reach the ruptured vessel and certainly will not penetrate thus far unless the patient performs forced inspiration and assumes the proper position, both of which efforts are fatiguing and likely to cause cough. However, I have mentioned the observations of Zdekauer showing the possibility of a solution like the terchlorid reaching the bleeding point, and Fisher has recently published encouraging results.

SILVER NITRATE ($AgNO_3$)

This salt in 0.05 to 0.50 per cent. solution has been recommended in **tuberculous laryngitis,** in **obstinate chronic pharyngitis,** in **granular pharyngitis** (Lewin), in **pulmonary tuberculosis** (Joseph), in **bronchial catarrh** and in **whooping-cough** (Rohn). Although the treatment is at present almost abandoned, I have often used it. While it is not to be advised in secondary syphilis, I have known it to be of great service in the treatment of late **syphilitic lesions** of the **mouth, pharynx, and larynx.** It has given me the best results in certain extremely obstinate, **painful forms of chronic pharyngitis,** often seen in patients suffering from eczema. It is important to begin with a weak solution, increasing the strength of the application very gradually, and reducing it at the first symptom of irritation; for these throats are remarkably intolerant.

In the same class of remedies, I may mention ALUMINUM NITRATE, which in 1 to 3 per cent. strengths has been tried by Beigel in **acute inflammations** and **nervous affections** of the **larynx and trachea;** ALUMINUM CHLORID (ten drops in 100 grams of water); IRON ALUMINATE, 0.70 per cent. (Morell Mackenzie); COPPER SULPHATE which has been recommended in cases of **chronic coryza** in solution of 0.1 to 1 per cent. (Vogler), **pharyngo-laryngeal ulcerations** (DaCosta) and **pulmonary gangrene** (Trousseau); IRON SULPHATE, 0.70 per cent.; ZINC SULPHATE, and SULPHO-CARBOLATE—1 to 5 per cent.—used in cases of **pharyngitis with profuse secretion** (Türck, Siegle, Lewin), in **subacute and chronic laryngitis** (J. Solis-Cohen), **chronic bronchorrhea** (Fieber) and in **rhinitis with profuse secretion;** LEAD ACETATE—0.45 per cent. —highly praised in **pharyngitis with obstinate cough** and in **pulmonary tuberculosis with a tendency to diarrhea** (Waldenburg); ZINC CHLORID —0.40 per cent.—which is especially useful in cleansing and disinfecting **putrid ulcerations,** more particularly **cancer.**

The mention of ERGOTIN and the EXTRACTS OF RHATANY, HEMATOXYLON, HAMAMELIS, KRAMERIA, CATECHU, etc., (Bataille) completes the list of astringents.

SEDATIVES AND ANESTHETICS

Among these it is necessary to distinguish: (*a*) Drugs that are effective in aqueous solution; (*b*) drugs soluble in other than an aqueous menstruum; (*c*) substances that vaporize and form a spray spontaneously under ordinary conditions of temperature and pressure.

(A) Drugs Active in Watery Solution

At the head of these we must place WATER itself, the sedative action of which is well known. In a goodly number of cases in which various solutions are employed by atomization I need only repeat what was said about inhalation, namely, that the effect produced is largely, if not entirely, due to the *hot water*. The atomization of water, *cold or ice-cold*, has been recommended (Zeitz, Waldenburg) as a sedative, and even as a sorbefacient in **simple acute tonsillitis.** It is also advocated in cases of **hemoptysis** (Fieber). Spraying with *hot water* is indicated in all **acute catarrhal inflammations** of the **upper portion of the respiratory tract** and good results have even been obtained in the **first stages of acute bronchitis.** In all **chronic diseases of the respiratory mucous membranes** such as **pharyngitis, laryngitis, dry bronchitis,** it has especially a **sedative action,** in the sense that there follows its use a diminution of the painful sensations of dryness and irritation, the cough is lessened and expectoration is facilitated. Sprays of hot water have been employed with the same success as steam in the treatment of **spasm of the larynx** and especially in **catarrhal croup, membranous croup, and laryngeal diphtheria** (Siegle).

The physiologic experiments that have shown the great absorptive power of the respiratory mucous membrane had their origin in attempts to supply by means of atomization the water lost during attacks of depleting diseases like **cholera, and excessive vomiting** (Witmeyer). As has been said before, it is especially and, unless we rely on clinical reports, I may add, exclusively, the water, to which must be credited the sedative effects attributed to sprays of the infusions and decoctions of the ROOT OF MARSHMALLOW, of VERBASCUM, THAPSUS OF MULLEIN, of the FLOWERS OF MARSHMALLOW and of PECTORAL FLOWERS in the strength of 10 to 20 parts in 500, which have been so much vaunted in the treatment of **acute and chronic catarrh, with dry, painful cough.** In the same class of cases, solutions of GUM ARABIC, 2 to 4 per cent. (Leiblinger), and GLYCERIN, 8 per cent., have been employed.

GLYCERIN has been used in large doses, and even undiluted, with the expectation of relieving congestion of the tissues by osmosis, especially in lesions of an edematous character. It has been particularly recommended in certain forms of tuberculosis and syphilis of the larynx; but, as Gougenheim and Tissier have shown, the dehydrating property of glycerin can be of no use in these two maladies, as the infiltrate consists, not of serum but of cellular elements. Glycerin has been abandoned by its advocates in whooping-cough, diphtheria, and tuberculosis, and it

has given me no encouraging results, except in **painful ulcerations of the pharynx,** where it has the not inconsiderable advantage of suppressing the fetid odor (J. Solis-Cohen).

HYDROGEN DIOXID (H_2O_2), which was introduced by B. W. Richardson in 1858, but neglected by physicians in general until some thirty years later, has give excellent results in the treatment of **catarrhal affections** of the pharynx and larynx without exudation; in **ozena,** in **hemorrhage** from the nose, mouth, tonsils, pharynx and larynx, in **Vincent's angina,** in tuberculous, syphilitic and other forms of **chronic ulceration** of the nose, pharynx and larynx, especially if there be profuse fetid secretion. It is also highly recommended by American physicians for use in **tonsillitis,** in **diphtheria,** in the **angina of scarlet fever** and in other bacterial diseases of the throat and nose. It is necessary to employ, not water charged with oxygen, but water oxygenized, in the proper sense, to from 3 to 12 volumes. The antiseptic property (Regnard, Paul Bert) and deodorizing power of hydrogen dioxid easily explain its action. It is well to remember that sprays of hydrogen dioxid from apparatus like Siegle's, or other of the same type, sometimes fail to accomplish their purpose, undoubtedly because of the decomposition of the unstable solution itself; we therefore make use of an apparatus of the Bergson or Richardson type. Hydrogen dioxid produces a rather disagreeable sensation; the saliva becomes thick, making a white foam; therefore the applications should be short and frequent. The solution must be not too highly acid, especially when mineral acids are used; I now employ exclusively a solution made stable with boric acid. The use of hydrogen dioxid should not be continued too long, or it may become destructive to the epithelial surface.

CARBONATED WATER produces an agreeable sensation, a feeling of well-being and comfort; it has often been advised after **laryngeal fatigue,** from declamation or singing.

SODIUM CHLORID SOLUTION, which I always prescribe in the strength of 7.7 grams in a liter (about one dram in a pint) that is, a physiologically isotonic solution, is the best agent I know of for facilitating the loosening of mucus, when tenaciously adherent to the mucosa, in cases of pharyngitis. The solution being non-irritating may be used to advantage in all cases of **chronic pharyngitis,** but particularly those of nasal origin, and in certain varieties of **dry laryngitis** and **tracheitis** with the production of scabs or of tenacious mucus. Saline sprays have also been advised in **chronic bronchitis** (Waldenburg) and in **pulmonary tuberculosis** (Lewin). Rossbach inclines to the view that saline sprays act like those of plain hot water only. When saline solution causes pain

recourse may be had to **alkaline solutions,** such as SODIUM CARBONATE, SODIUM BICARBONATE or SODIUM BORATE.

SODIUM BICARBONATE, in 0.2 to 2 per cent. solution, has been recommended in **chronic rhinitis** with scanty, tenacious secretion, in **acute tonsillitis** (Waldenburg) and in valvular affections of the left side of the heart (Gerhardt) with **bronchopulmonic stasis.**

POTASSIUM BICARBONATE has been tried in cases of recent **catarrhal bronchitis** and **laryngitis** (Siegle), in **pneumonia, whooping-cough** and **croup.**

POTASSIUM CHLORATE or, better, POTASSIUM CHLORID, in atomized form, is indicated in all cases in which it is usually employed by swabbing; acting more thoroughly and more promptly. Weak solutions, 1 per cent., should be employed. I need not dilate upon its usefulness in **diphtheria;** it has an undeniable effect in all **ulcerations** of the bucco-pharyngeal cavity; it is especially useful in **apthous stomatitis,** in **ulcero-membranous** and in **mercurial stomatitis.**

SODIUM CHLORATE is employed in the same way as the potassium salt.

AMMONIUM CHLORID, in 0.25 to 2 per cent. solution, has been strongly recommended in **pharyngitis sicca** (J. Solis-Cohen), in **catarrhal laryngitis** (Siegle), in similar affections of the **trachea** and the **bronchi** (Siegle, Lewin), and in **pulmonary tuberculosis** (Gerhardt). In superficial catarrhal diseases of the air-passages Waldenburg advises the use of the following formula:

Ammonium chlorid, ...	25 parts
Distilled water,	
Glycerin, each, ...	100 "

One or two tablespoonfuls to a glass of water, for each spraying.

LIME-WATER in 20 per cent., 60 per cent., even 100 per cent. solutions has been employed, especially in **diphtheria,** as a means of dissolving false membrane (Kuchenmeister, Biermer), it having no apparent action on the bacilli (Chantemesse, Widal). Similarly its use has been suggested in **pseudo-membranous bronchitis** (Waldenburg).

ANESTHETICS AND ANALGESICS

Of the many substances that have been used to allay pain and irritation or to subdue cough, I shall mention a few of the more important; first those employed in **aqueous solution.**

OPIUM in the form of the tincture—0.1 to 0.5 per cent.; of the extractum thebaicum—0.02, 0.10 to 0.20 per cent.; of the deodorated tincture—0.1 to 1 per cent.; of morphin—0.005 to 0.05 per cent.—

has been recommended only in **painful affections** of the pharynx and larynx (Fisher). J. Solis-Cohen has used it to advantage in cases threatening **edema of the larynx.**

BELLADONNA in 0.01 to 0.05 per cent. solutions of the extract has been employed especially for **spasmodic affections:** spasm of the glottis, laryngismus stridulus, spasmodic cough (Sales-Girons, Blake), and dyspnea due to emphysema (Waldenburg). Atropin is rarely used because of its extreme toxicity.

HYOSCYAMUS—0.05 to 0.2 per cent. of the extract—has been employed in the same conditions in which belladonna has been used, but, in addition, it has been recommended in **chronic phthisis** as an excellent sedative (Leiblinger, J. Solis-Cohen).

Mention must be made of CANNABIS INDICA (Leiblinger) and of CONIUM in **hyperesthesias** of the laryngeal mucous membrane (Lewin, Waldenburg); of STRAMONIUM in **asthma** and **emphysema** (Waldenburg); of LOBELIA in **asthma** (Lewin); and of WINE OF IPECAC in obstinate **laryngeal** and **bronchial coughs** (Ringer).

HYDROCYANIC ACID, used generally in France under the form of CHERRY-LAUREL WATER (aqua laurocerasi), from 2 to 5 per cent., has been recommended by Morell Mackenzie in rather large doses. For the same purposes one may use the OIL OF BITTER ALMONDS (Lewin).

COCA.—Formerly the infusion of the leaves (8 per cent.) was utilized; nowadays COCAIN HYDROCHLORATE in 0.2 to 10 per cent. solution is substituted. I wish to call attention, however, to the possibility of accidents from sprays of this solution. The anesthetic effect is rapid and complete, but its duration is short, so that frequent applications are required and the increased tolerance necessitates increased doses. I therefore prefer its application with a swab.

POTASSIUM AND SODIUM BROMIDS (1 to 5 per cent.) sometimes give excellent results. Occasionally ANTIPYRIN (2 to 5 per cent.) is employed for its analgesic effect; the last-named drug is of especial value in some cases, because of its hemostatic property.

(B) ANALGESIC AND ANESTHETIC SUBSTANCES IN OTHER THAN AQUEOUS SOLUTION

OIL in general, represents the vehicle best tolerated. Oils have been employed without the addition of other substances, pure or in emulsion: OLIVE-OIL in **phthisis, emphysema, whooping-cough;** OIL OF SWEET ALMONDS in spasmodic cough; COD-LIVER OIL in **tuberculosis.** More often, however, these oils are used as vehicles for other active substances, such as MENTHOL, CREOSOTE, GUAIACOL, THYMOL, EUCALYPTOL, and the like.

It is difficult to assign a place in our classification to those substances which are both **analgesic** and **antiseptic.** Without insisting upon strict consistency, we shall study them here:

Atomization with oily solutions containing menthol, creosote, and guaiacol is performed with any efficient nebulizer, preferably one of the Oliver type. A Bergson or Richardson tube with a sufficiently large orifice, however, suffices with the generality of solutions. There is no doubt of the efficacy of these sprays in **acute catarrhal inflammation** of the pharynx, larynx, and trachea. It is unnecessary to repeat what has been said about menthol applications; as for creosote and guaiacol, which I sometimes combine with menthol, they have often served very well, particularly CREOSOTE, which is the surest and most efficacious application whenever an effect on the laryngeal or tracheal mucosa is desired. In **pulmonary tuberculosis,** its value is, in my opinion, not so well established.

(c) VOLATILE SUBSTANCES that can be used by self-atomization through a fine opening in the container (ESSENTIAL OILS, ETHYL and METHYL CHLORIDS, ETHER) are few in number. Seldom employed, they are applicable in spray form to the air-passages, only when a limited area is to be treated, as in the mouth. COCAIN and other agents are sometimes dissolved in ethyl chlorid for this purpose; the freezing effect must be kept in mind.

ANTISEPTICS

I shall limit myself to a very brief account, not wishing to lengthen this chapter unnecessarily.

CAMPHOR (Fieber) has been employed in cases of **phthisis** with fetid expectoration; the OIL OF TURPENTINE has been used in similar conditions (Waldenburg), as have also the oils of COPAIBA and of CUBEB (Trousseau).

OIL OF EUCALYPTUS (oil of eucalyptus, 5 parts by weight, alcohol, 25 parts; distilled water, 170 parts;—for ten sittings) has been extolled in **diphtheria** (Mosler), in chronic diseases of the **bronchi,** and in **tuberculosis.**

OIL OF TAR is considered by Siegle and Waldenburg an excellent antiseptic, meeting the same indications as turpentine.

CREOSOTE. Reichenbach, who discovered this drug in 1830, was also the first to suggest its employment in the treatment of **tuberculosis** He described two cases of hemoptysis successfully treated and asked the question, Would it not serve a useful purpose to place a patient

suffering from phthisis in an atmosphere charged with the vapor of creosote? Granting that the vapors of creosote he added, do not reach the ulcerations themselves, they may arrive at the edges of the lesions, and thus aid nature in combating the disease. He used, not atomization, but a simple saturation of the air with the vapor of creosote, obtained by placing in the sick-room pieces of paper soaked in the drug. Martin-Solon, 1835, experimenting with the aid of a Woulff bottle, failed in the use of creosote entirely and believed that he was justified in proclaiming its entire uselessness. His decision, was not uncombated; but many years elapsed before new champions of creosote appeared (Bouchard and Gimbert). Fraentzel utilized the inhaler of Feldbausch to carry the creosote vapors to the larynx and lung; his results were not encouraging, because of the feeble volatility of the drug at low temperatures. Its bactericidal action, however, is undoubted.

Creosote mixed with tuberculous expectoration diminishes its virulence (Coze and Feltz). In cultures it diminishes the vitality of the bacilli (Guttmann), preventing their development even in weak solutions, 1 : 2000 to 1 : 4000. Villemin did not find that the vapors of creosote caused any change in cultures on agar. These experiments, somewhat contradictory, are explained in part by the fact that the bacilli used were of different origin (from human, bovine, and avian tuberculosis).

The **method of treatment by creosoted air** has been excellently described by M. Lesguillon.

In a little room of about 150 cubic meters (50 cubic feet), containing six beds, a continuous vaporization is maintained by means of an apparatus, the solution used being variable in strength. The mixture is the following:

Creosote (beechwood),	10–20 parts by weight (maximum)
Alcohol,	200 "
Glycerin,	20 "
Water,	770 "

Up to 12 liters of this solution are used during twenty-four hours. It is important not to carry the concentration beyond 2 per cent., as beyond that point the air becomes difficult to breathe, and other phenomena, such as irritation of the conjunctiva; smarting of the throat; oppression; sneezing, and cough, declare themselves. The patient remains in this same room, the temperature of which is carefully maintained.

This creosoted atmosphere is well borne by patients, who quickly

become accustomed to it, without experiencing even an initial bad effect. One of the first effects is an improvement in the expectoration; it becomes less difficult, less abundant, more liquid. The cough diminishes rapidly in frequency and in severity, but not in all cases; at times slight irritation of the air-passages (irritation of the pharynx, spasmodic cough, and even exacerbations of bronchitis) is observed. It produces no tendency to hemoptysis and some cases of recent hemorrhage can undergo the treatment with impunity. The local signs become modified, the lesions show a tendency to dry and to become circumscribed. This favorable result is observed only in cases with slight pyrexia; in patients suffering from tuberculosis with high fever there is no improvement; this is also true of advanced cases.

The CARBOLIC ACID SPRAY, 0.5 to 3 per cent., which, for twenty years from the first publication of Lister, was employed so largely in surgery, has been tried, in the majority of the diseases of the air-passages with only moderate success. Abandoned in diphtheria and tuberculosis, it is used nowadays for **foul-smelling lesions** only. Its action is perhaps most useful in relieving the **pain** due to certain lesions of the pharynx and larynx.

RESORCIN, 1 per cent., praised in **whooping-cough,** is particularly useful in **chronic affections of the pharynx,** with subacute exacerbations.

SALICYLIC ACID, 0.1 to 0.5 per cent., has served me excellently in **herpes of the pharynx** and in **phlegmonous tonsillitis** both at the beginning and after the abscess has been opened.

I shall merely mention SODIUM BENZOATE, 3 to 5 per cent., which had an ephemeral vogue (v. Rokitansky); THYMOL, 0.05 to 0.1 per cent., administered in **whooping-cough;** CHLORIN-WATER (see page 327), recommended in **bronchitis** with profuse expectoration and in **tuberculosis** (DaCosta), which has the disadvantage of being irritating when used in therapeutic strength, 1 to 10 per cent.; IODIN-WATER (Siegle), used to meet the same indications as the inhalations of iodin; BORIC ACID, 2 to 3 per cent., which acts almost only by the steam; CORROSIVE SUBLIMATE, 0.02 to 0.25 per cent., which has been strongly advised in the common forms of **laryngeal tuberculosis,** with infiltration and ulceration, and in **syphilis** of the mouth, throat, and larynx (Demarquay, Schnitzler, Siegle, etc.); SULPHUROUS ACID, 10 to 50 per cent., useful in **septic affections** of the upper air-passages (J. Solis-Cohen); LACTIC ACID, 1 to 50 per cent., advised in **croup** (Bricheteau), and more recently recommended for **tuberculous ulceration** of the mucosa of the mouth, pharynx, and larynx; POTASSIUM IODID, 0.2 to 5 per cent., employed in **chronic catarrhal diseases** (Siegle), **tuberculous lesions** (Lewin) and particularly

syphilitic lesions of the pharynx and larynx (Waldenburg); IODOFORM (emulsion 10 per cent.), used for **tuberculosis of the larynx,** etc.

QUININ HYDROCHLORATE, 0.02 to 0.2 per cent., has been tried in **whooping-cough and hay-fever;** ANTIFEBRIN or ACETANILID, 0.06 to 7 per cent., has been utilized by Schtscherbaker in the hope of reducing the temperature in **phthisis.**

Finally, I may mention the inhalations of cultures of BACTERIUM TERMO (bacteriotherapy) tried by Cantani in the treatment of **tuberculosis.**

THERAPEUTIC EFFECTS OF ATOMIZATION

The therapeutic effects of atomization vary, not only with the drugs employed, as I have indicated in the preceding section, but also with certain conditions which I shall now briefly discuss.

These conditions relate primarily to the **apparatus** used, to the **pressure** employed, to the **tenuity** of the liquid particles, and to their **temperature.** One readily perceives that the quantity of liquid entering the air-passages varies according to the form of apparatus employed and the distance of the patient from the tip of the atomizer. So soon as the solution enters the air-passages, its temperature tends to approach that of the interior of the body; if the latter be the lower, there results a cooling, with condensation; but if it be the higher, the liquid undergoes a rise in temperature with the production of vapor. In order to have a satisfactory appreciation of the effects note must be taken of these various factors; and this is one of the reasons that different authors have obtained divergent results under what seemed superficially to be the same conditions. At the beginning, this method gave rise to great hopes; hence the multiplicity of instruments and the considerable number of solutions employed. It did not come up to expectations, however, and latterly has been somewhat undeservedly neglected. This is not the only remedial measure in which an unjustifiable enthusiasm at the beginning has had a bad effect. It should not be demanded of a therapeutic procedure that all anticipations be realized, rational though they may appear *à priori.* The rôle of physiologic investigation in therapeutics is to establish, first, the dynamic effects of a procedure; and then, with these data fixed, to search for their application.

General Conclusions

Whenever the stream can reach the diseased area directly (*e. g.*, in **nasal, tonsillar, pharyngeal, or epiglottic lesions**) the method is sure and of great value, and in most cases is to be preferred to others. It

is of incontestable value in affections of the **larynx**, particularly in those of a painful nature. Atomization also facilitates the expulsion of mucus. When the remedy is employed regularly, as in tuberculosis, the objection has been raised that the suitable position is distressing to the patient, and that, to accomplish the penetration of the liquid, deep inspirations are necessary, which produce cough. In connection with the application of mineral waters, we shall see how necessary it is to refrain from *à priori* reasoning.

We may **sum up** by saying that often the best and surest therapeutic method in **laryngeal diseases** is atomization, and that it sometimes gives results impossible of attainment by any other means in the treatment of numerous **diseases of the bronchi and lungs.**

ON INHALATION METHODS IN THE EMPLOYMENT OF MINERAL WATERS AT THEIR SOURCE

Inhalation, in its general sense, has been employed for a long time at numerous **thermal springs.** This is true especially of **sulphur** springs; but the method is also used at other resorts. In addition to sodium chlorid waters, we shall mention, of French resorts:

THE ARSENICAL WATERS OF LA BOURBOULE, where the atomization method is largely employed and, it may be added, with very great success.

THE GASEOUS (CARBONATED) ARSENICAL WATERS OF MONT DORE, containing but a small amount of mineral constituents, where there is in operation an inhalation method that has been described by Percepied. The **inhalation** is performed at a variable temperature—according to the chamber selected, at 28° C. (82° F.), 30° C. (86° F.), or 32° C. (90° F.). Patients go in the morning only, remaining in the chamber for from twenty minutes to an hour, and are then taken back in sedan chairs to their residences, where they lie down for at least an hour. In the inhalation method practised at Mont Dore, the water is not atomized, but **vaporized.** The mineral water is boiled in a cylinder with the aid of steam under high pressure; the vapor given off is conveyed into a special apparatus, also supplied with mineral water. which in its turn is volatilized and is transmitted to the inhalation chambers. The effect of the first procedure is not only to vaporize the water; the heat also decomposes the alkaline bicarbonates, supplying a considerable quantity of carbon dioxid (0.008 gm. to the liter), which possesses a definite medicinal value. This carbon dioxid carries with it some solid particles from the bodies with which it is mixed or associated—arsenic,

sodium salts, iron, etc., not by sublimation, but by mechanical force. The second part of the procedure increases the mineral constituents of the vapors. Thenard and Bertrand have very exactly incorporated in the water of condensation, iron, sodium salts, and arsenic.

In addition to vaporization, **atomization** is likewise practised; **humage** also is made use of, by the direct inhalation of gases arising from the springs. It is fair to admit that at Mont Dore the baths and the drinking of the waters (balneotherapy and crounotherapy) have much to do with the effects of the treatment; to say nothing of the conditions afforded by an altitude of 3000 feet; but it is no less well established that to inhalation and atomization belongs a large part of the credit for the remarkable cures in cases of **asthma, emphysema, chronic bronchitis, tuberculosis** with congestive dyspnea, **chronic laryngitis, chronic pharyngitis,** and **rhinitis.**

The waters of Paderborn and of Panticosa, are discussed in the article on Nitrogen on page 317. The copper sulphate waters of Saint Christau are referred to later.

The air of salt-mines and **saline springs** is also used for inhalation. The waters rich in sodium chlorid are led over *fascines* or graduating contrivances. Here the water filters and divides into tiny drops, which are scattered by the wind and evaporate. During this vaporation the air becomes impregnated with certain principles, and the patients breathe it in the promenades around the fascines of the salt-works. It is fresh, denser than the ordinary air, richer in oxygen and ozone, poorer in carbon dioxid. In addition to the vapor of water, it contains traces of iodin and bromin, and a large amount of sodium chlorid. On the patient it exercises a sedative effect, accompanied with slowing of the pulse and respiration, which become, respectively, fuller and deeper.

Sulphur Waters.—It is, however, with sulphur springs that we shall be here most concerned. Sulphur has been considered as a disinfectant since ancient times, and Ulysses purifying his abode with sulphur vapors is no less significant, symbolically, than the shower of sulphur falling upon the corrupt cities of Sodom and Gomorrah. Sulphur-containing waters have always been regarded as possessing marked curative properties. It was at a sulphur spring that Sales-Girons first put in operation the method of atomization.

Sulphur waters * are to be **classified** for our purpose as those containing sodium sulphid and those containing calcium sulphid; it is

* See, however, volume IX, p. 358.

necessary to call to mind this division, for on the nature of the waters depends their mode of therapeutic application in inhalation.

The SODIUM SULPHID WATERS are very numerous in France, on the northern slope of the Pyrenees: Luchon, Ax, Cauterets, Barèges, Saint-Sauveur, Eaux-Bonnes, Eaux-Chaudes, Amélie-les-Bains, Le Vernet, Molitg, Escaldas, Olette, La Preste, Carcanières, Castéra-Verduzan, Ussat, etc. Among the cold sodium sulphid springs: Cadéac-Arreau, Labassère, Gazost-Argelès. On the western slope of the Alps are: Marlioz, Uriage, Challes, and St. Honoré in the Nièvre. There are also numerous sodium sulphid waters in other countries: Harrogate, in England; Vizella, in Portugal; Harkany, in Hungary; Abano, Acqui, Vinadio, Battaglia, in Italy, etc. (See volume IX.)

Among the CALCIUM SULPHID WATERS may be mentioned: Enghien les Bains; Allevard; Pierrefonds; Euzet; Cambo; Saint-Boès. (See vol. IX.)

One of the properties to be observed in connection with the special viewpoint from which we are now studying this subject,—disregarding for the present the spontaneous liberation of nitrogen (see page 317) that occurs at many places and in especial abundance at certain springs in Spain,—*e. g.* Panticosa,—is the occurrence in certain waters of a spontaneous liberation of HYDROGEN SULPHID. This gas is liberated only gradually, in contact with the air, from the sodium waters, while it exists in a free state in the calcium waters, which are usually cold and more highly mineralized than the sodium waters.

HUMAGE

Sulphur springs are made use of, so far as we are just now concerned, by means of *humage*, inhalation and atomization. Ferras, the learned physician of LUCHON, where these methods are employed on the largest scale, describes as follows the indications for humage, its technic and its effects, as observed at that station:

In hydrology, inhalation and humage are far from being synonymous, and above all should not be confounded with atomization. The various apparatus for the last-mentioned are all designed to reduce medicinal solutions or mineral waters to a liquid dust or spray, and to direct them not only into the respiratory passages but also over other organs or large surfaces. Inhalation is a therapeutic procedure conducted for several patients in common, in chambers of which the atmosphere is more or less rich in mineral vapors; while humage is designed for the individual inhalation of natural vapors, warm, and spontaneously liberated by the passage of mineral water.

Humage is therefore a special inhalation arranged for the individual patient. Although for over a century humage has been prescribed at Luchon, it appears now to be limited in practice to the inhalation of sulphureted vapors and, even more, of **hydrogen sulphid.** This characteristic of Luchon is due to the mineralizing principle of its waters: sodium hydrosulphid (NaHS). The other hot sulphureted springs of France and other countries possess as an active principle sodium or calcium sulphid (NaS or CaS). Moreover, these last-named liberate vapors scarcely sulphureted and not able to afford a sufficient natural humage. To remedy this deficiency there have been installed in certain stations apparatus acting as breakwaters to promote the liberation of hydrogen sulphid. There is thus obtained a very fine atomization, but not a true humage.

At Luchon, in the center of the Pyrenees, in the thermal stations of the first order, says Durand-Fardel, and built on the same ground as the Roman baths (so celebrated through the writings of Strabo, 19 B. C.), there are utilized springs that are the hottest and the richest in hydrosulphids. In elevated rooms, well aired, these waters pass through small basins made of white, fine-grained marble. Each basin has a tube leading into it and a separate one leading from it. All the piping of the rooms, amounting to almost 1500 feet, is made of tubes of Limoges porcelain. The vapors emitted in consequence of the changeability of the springs ascend, because of the difference between the elevated temperature of the basins and the colder air of the rooms. They are collected by a chimney of marble capping the basin and terminating in a funnel-shaped orifice before which the patient breathes, without the slightest effort and not in the least inconvenienced by the steam, which is so slight in density that it is invisible except on cold days in winter. Moreover, there is no need to wear any special costume in these vapor rooms of Luchon, as one sees elsewhere in inhalation chambers. Frebault, the inventor of this ingenious and important installation, has arranged other apparatus which permit the graduation at will of the quantity of sulphureted hydrogen, of the steam and of the temperature, for one, two, and three minutes. All these apparatus, it is to be remembered, are only separators, without action on the changeability of the springs, which furnish spontaneously the vapors for humage at Luchon.

Each evaporating basin is divided into four equal parts. Each part may be opened or covered at will with a plate of nickeled bronze, grooved anteriorly. These plates or obturating valves are moved by a handle. The movement of the latter is transmitted by means of an

endless screw and of a toothed wheel to a vertical shaft. At the upper part of the structure is an apparatus registering the position of the valves in such a manner as to eliminate any error of the attendants, and also to allow the patient to assure himself that he is being given just the proportion prescribed by the physician. According as one uncovers the first, the second, the third, or the fourth small basin, one receives, respectively, one-fourth, one-half, one-third, or all, of the vapors escaping.

In other apparatus the valves, instead of being exactly above the surface of evaporation, are placed at the end of the chimney that collects the vapors.

By regulating this escape of gases one can obtain, according to the indication, increase of hydrogen sulphid, with temperature and amount of steam practically unchanged; or on the other hand, sulphur gas in unchanged quantity, but increase in the heat and in the amount of steam, and the latter, we repeat, never enough to require a special costume.

At Luchon each patient inhales from his own apparatus, separately, and without any communication with his neighbors. The temperature of the vapors varies from 30° C. to 43° C. (say 86° to 110° F.) and the quantity of sulphur rises from 20 to 82 and 92 milligrams by gradations of 20, 30, 35, 40, 45, 50, 55, 60, 65, 70, and 75 milligrams to the cubic meter. These figures are based on standard temperature (0° C. or 32° F.) and pressure (760 millimeters Hg—15 pounds to the square inch.) The mineral richness of the vapors liberated can readily be demonstrated, for the finger passed over the interior surface of a chimney becomes coated with a layer of sulphur. In 1880 Ferras showed the tracheal cannula of a colleague blackened by silver sulphid after a few minutes of humage, while the part of the tube in contact with the musculo-aponeurotic canal had retained its metallic luster.

Effects of Humage.—Comfortably seated before the funnel, the patient inhales quietly, at the distance prescribed, for the lips should not touch the apparatus. From the first a sensation of gentle warmth penetrates the chest. Respiration becomes deeper and easier. The patient experiences a certain sense of well-being that induces him to accept this mode of treatment with pleasure—a feeling so pleasant, in fact, that he might easily be led to continue the sitting for too long a time, which would produce a sensation of heat, dryness, and discomfort in the larynx. But this is to be noticed, that patients never cough from the effects of humage; on the contrary, their dry and troublesome cough is made less troublesome by the

process, the action of which is very definite in all cases in which the expectoration is thick and abundant. It quickly becomes scantier and more watery, and the sputum no longer sinks in the water of the cuspidors as at the beginning of the treatment.

Sulphureted hydrogen being the basis of the humage treatment, the antimicrobic, antitoxic effects of this gas are made apparent by the rapid amelioration of all the chronic catarrhs of the respiratory passages. The absorption of the sulphur adds its general tonic action, which is augmented by the sulphur baths, showers, and drinks. The climatic condition of the valley of Luchon, surrounded by forests of fir-trees, deserves also to be mentioned, for it is of importance with delicate larynges and bronchi.

Principal Indications for Humage.—The affections which derive the most benefit from this special treatment are: **chronic arthritic coryza; chronic laryngo-pharyngitis; chronic bronchitis, dry or moist; emphysema in its early stages**; and **asthma,** especially the '**moist**' form. The vapors may also be utilized with excellent effect in catheterizing the Eustachian canal for the treatment of **chronic affections of the drum membrane.** Lastly, since 1890, humage at Luchon has proved its efficacy among numerous patients suffering from **influenza.** The results obtained at this station have been described by Ferras in notes registered at the Academy and comparing the action of various classes of mineral waters on the now well-known manifestations of influenza. As the disease invades the system through the respiratory passages, humage is certainly one of the best means of protecting the mucous membrane against the bacillus of Pfeiffer.

SPECIAL FEATURES OF INDIVIDUAL RESORTS

Inhalation is the special therapeutic feature at Allevard, and is also employed at Challes, Marlioz, St. Honoré, and other resorts. At Allevard the inhalation is administered in cold rooms, that is to say, at the temperature of the external air, or in rooms warmed (27° to 30° C.—80.6° to 86° F.) by the vapor of sulphur water escaping from the floor into the open space. In all the rooms, since the first installation of Niepce (1852), the liberation of sulphureted hydrogen is accomplished by the impact of the water striking in a jet against a cap in the ceiling of the rooms, and then falling from basin to basin and into the lowest basin, which is the largest—thus multiplying the surfaces of evaporation. The patients, seated upon benches, are clothed in bath gowns, and inhale for two, four, six, eight, ten, or twelve minutes, after which

they lie down in the so-called transition room. Four to six séances daily are prescribed. On entrance into the inhalation room one encounters a strong odor of hydrogen sulphid, and a tickling sensation in the larynx provokes a cough; but toleration is acquired rather quickly. The séances should not be too prolonged, lest there appear signs of intoxication, even to the extent of syncope, Between the séances there should be an interval of at least ten to fifteen minutes.

Indications.—The efficacy of the treatment is manifest upon **recurrent bronchitis; chronic catarrh,** with or without **emphysema; asthma;** the sequels of **influenza; pulmonary tuberculosis,** except in cases of a distinctly febrile character; the **chronic** forms of **rhinitis; inflammation** of the **frontal and maxillary sinuses;** remnants of **adenoids; chronic pharyngitis; catarrhal** and **tuberculous laryngitis; hay-fever;** the **sequels of rubeola** and **pertussis,** etc. The beneficent action on the cough, the dyspnea, the expectoration, and the general nutrition is to be attributed to the **reducing action of the hydrogen sulphid,** which, in contact with the bronchial secretions, takes up the water and deposits its sulphur.

At CHALLES, only **cold inhalation** is practised, in a room where the jets of sulphurous water, thrown against a metallic cupola, saturates the atmosphere with hydrogen sulphid.

It is necessary not to confound, in our conception of the absorption processes and of the therapeutic effects, the methods that consist, on the one hand, in the respiration of air charged with gas naturally produced by mineral springs, and, on the other hand, of the inhalation of forced vapors escaping from a generator, and carrying nothing, or almost nothing, of the principles which constitute the mineral water from which they come.

At ST. HONORÉ, **inhalation** is especially made use of. The procedure here has varied at different times. At first there were used vapors escaping spontaneously from the water at 31° C., 87.8° F. (Roman reservoirs), but the quantity of hydrogen sulphid liberated was scarcely appreciable in the rooms. In 1859 the idea was conceived to have the water from the springs pass through wells in jet or cascade; a horizontal hydraulic wheel with spiral plates, constantly turning at the bottom of the shafts, desulphureted the water at its own temperature, as it was thrown in the air. Considerable advance was made when the water was led through the top of a tube (Collin), from which it fell, dividing more and more finely, from waterfall to waterfall, through three superimposed basins. Another arrangement consisted

in a bulb, 30 centimeters in diameter, pierced in its upper part by several rows of very fine apertures; the water was thrown into a thousand jets which, issuing from the sphere, gave off their sulphureted hydrogen as they fell against the interior walls of the shafts (Collin).

At St. Honoré **catarrhal affections** of the nose, pharynx, larynx, trachea, and bronchi are treated with great success, but the special indication for the treatment at that resort is **pulmonary tuberculosis.**

At EUZET, Gard, where there are sulphur and, especially, bituminous waters, the treatment is conducted in **inhalation** and **atomization** rooms. The patient remains in the inhalation room at least an hour; there the most marked sensation he experiences is a strong petroleum odor, which appears to take hold of the throat and at once produces a rather disagreeable effect. It is in the treatment of rebellious **anginas** and especially of **tuberculosis** that the medication at Euzet has been recommended (Bonnajoy).

We cannot here describe all the stations, but proceed now to those where the process chiefly employed is **atomization.** We say chiefly, because in most stations atomization, inhalation, and sometimes humage are associated or combined. Thus at CAUTERETS there are employed both **inhalation and atomization** (Ferras). There is used the water from the César spring, the sulphur complement of which is diminished only from 10 per cent. to 12 per cent. by the impact and pulverization of the water. At PIERREFONDS, the birthplace of the atomization method, and at Enghien, near Paris, atomization chambers are in operation.

At ENGHIEN, two rooms are especially arranged for combined **inhalation** and **atomization.** The sulphur water of the Lac spring is compressed by pumps to 30 atmospheres; it escapes through filiform tubes in numerous apparatus (fifty in each room) and breaks into a fine spray. The room is filled with this spray, in the midst of which the patients walk about, protected by water-proof garments. They can also seat themselves from time to time before the apparatus at a distance of eight to twelve inches, and receive directly into the throat a veritable douche of sulphur in powder. **Atomization chambers** are installed in most of the sulphur stations. It is indisputable that the sulphur atomization, employed to the exclusion of all other treatment—as I have often observed in the case of my patients sent to Enghien, where the proximity to Paris eliminates from consideration any result that might be attributed to the change of surroundings or of alti-

tude—exercises a distinctly beneficial effect not only in **catarrhal affections of the upper air-passages** but also in cases of **chronic bronchitis** with abundant secretion, of **emphysema,** of **asthma,** and of certain unprogressing forms of **pulmonary tuberculosis.** The lingering effects of a **grippal infection** also yield rather readily to the treatment.

THE COPPER SULPHATE WATERS OF SAINT CHRISTAU.—Before concluding the discussion of the employment of mineral waters in atomization, a word should be said concerning a special sulphate spring, Saint Christau. It is a COPPER SULPHATE water. The chemical characteristic of the water of the principal spring, the Arnaux, is the presence of the copper, which appears to be the preponderating agent, the other elements existing, apparently, only in unimportant proportions. **Atomization** has acquired at Saint Christau a special importance, and constitutes in many cases the basis of the thermal treatment. An instrument appropriate to the nature and localization of the lesions treated, allows the regulation at will of the temperature of the sprays and the **graduation** with precision of their force, quantity, and fineness.

Indications.—The Saint Christau cure in a general way exercises an especially advantageous action on **chronic inflammatory processes** of the congestive, ulcerating, varicose, or proliferating forms, or the form with diminished secretion, in which there is alteration of the function of epithelia of the skin and of mucous membranes of the Malpighian type. **Leukoplakia** or buccolingual leukokeratosis (the buccal psoriasis of Bazin) occupies first place among the indications for St. Christau treatment. In this condition rapid and truly marvelous results are obtained, even when all other medication has proved futile. The **syphilitic lingual scleroses,** so often associated with leukoplakia, complicated or not with fissures or ulcerations, also find in the St. Christau cure a very efficacious treatment. Among the indications of the second order are to be mentioned **desquamative glossitis, chronic non-hypertrophic rhinitis, chronic pharyngitis,** and even **cancer of the tongue** when it has passed beyond the operable stage.

CHAPTER VI

INHALATION AND INSUFFLATION OF POWDERS (SPIROTHERAPY)

General Historical Review. The Penetration of Powders. Insufflation Methods. Instruments. Pharmacology. General Indications.

General Historical Review

Solid substances cannot be introduced into the air-passages unless very minutely powdered. The inspiration and insufflation of powders is a method by no means modern, since Galen credits to Æsculapius the use of powders in the treatment of diseases of the respiratory passages, particularly acute inflammatory conditions of the throat; myrrh and nutgall were preferred. J. Solis-Cohen has given a thorough résumé of the subject in his admirable treatise, and in what follows I quote largely from him.

Aretæus of Cappadocia in the fifth century used this form of medication, particularly in laryngeal affections of children. Darwin, Niedermayer, and, later, Trousseau and Belloc, saw good results from the inhalation of powders. The latter authors, as also Burow, used the sugar of milk as a vehicle for the active drugs. Burow praised this method highly in cases of **chronic laryngitis.** Pserhofer applied the principles set forth by the authors mentioned not only in the treatment of diseases of the larynx but also in those of the **trachea, bronchi,** and **lungs.** He went so far as to advise the method for the introduction of remedies intended to act on **distant organs.**

The development of **laryngoscopy** has been the means of substituting for inhalation, **direct insufflation,** under the guidance of the eye, of powdered medicaments introduced by apparatus especially constructed for the purpose. The instruments of Gilewski, Rauchfuss, Mandl, Chambon, Fournié, and others differ but slightly from one another.

Chambon suggested the use as a vehicle of an inert powder without any irritating action upon the air-passages, and with this in view selected LYCOPODIUM, which he impregnated with the active remedy. CINCHONA, and ACETATE OF LEAD, used undiluted, have been recommended by Dickson. Thomas, of Baltimore, conceived the plan of inhaling pow-

dered SILVER NITRATE as fast as it is produced; for that purpose he used the silver nitrate stick held in contact with a rapidly revolving grindstone. At the present day both inhalation of powders and insufflation are used at times in the treatment of affections of the nose and pharynx, penetration of powders in these regions being generally admitted. For the epiglottis, the larynx, and the trachea the same holds true, provided direct insufflation is practised by the physician under the guidance of the mirror.

THE PENETRATION OF POWDERS

The question whether it is possible to carry to the bronchi and lungs solid matters in a finé state of subdivision is of great importance. This possibility has long been popularly believed, and indeed upheld by many physicians. Pliny mentions that miners and bakers, fearing the entrance of dust particles into their respiratory passages, took suitable precautions.

Anatomico-pathologic Proofs.—Every physician practising among laborers employed in occupations associated with the production of dust, has remarked the frequency of pulmonary diseases among them; Ramazzini (1777) remarked that stone- and marble-cutters are subject to certain affections of the lungs and have an acquired tendency to phthisis or asthma, and explained this fact by the entrance into the air-passages of the fine particles of stone. Dumersbrock, Erdman, Petrenz, Loeve, and Brockman make similar statements. Pearson was the first to study precisely the question of the origin and nature of the black substance that so frequently infiltrates the lungs and bronchial glands of adults. He remarked that this pigmentation increased with age, that its substance was very resistant to the strongest reagents, and he concluded that it was due to particles of coal-dust inhaled with the atmosphere. Graham having found the lungs of miners who had been killed by accident, black in color, had analyses made by Christison; the latter found that this black pigment resisted the action of hydrochloric and nitric acids, and concluded that it was not organic, but was a foreign substance carried into the economy. Laennec did not hesitate to identify it with coal, this being in accord with Fourcroy and opposed to the view of Broussais that it was a degeneration product due to age. Laennec attributed the black discoloration of the lungs to the inhalations of fumes from the miners' lamps. With Broussais, Bichat, Breschet, Trousseau, LeBlanc, Virchow himself in his earlier works considered the discoloration of the lungs as mere pigmentary alterations,

his chief argument being the presence of the same coloration in some subjects on the surface of the costal pleura and regularly in the bronchial glands. Traube set about to determine definitely by convincing proof the vegetable nature of the black dust in the lung (1860–1867). It is certain that dusts do not supply all forms of pigmentation of the lung; some may be due to changes in the pigment from extravasated blood; but clinical observation of Traube's patient, followed by a microscopic examination by Cohnheim and Rindfleisch, demonstrated first in the sputum, and later in the pulmonary tissue, dust composed of wood-charcoal. In the sputum was found a characteristic cellule of carbonized fir-tree with seven canaliculæ side by side. Virchow, and then all other authors, soon accepted the fact as positively proved. Since then the different varieties of **pneumoconiosis, chalicosis, siderosis,** etc., have been studied, and Proust in his treatise on hygiene gives a table as complete as possible of the professions in which these dust-diseases are observed. Zenker, Charcot, Carrieu, Yun, and Ruppert have since described the morbid anatomy and physiology of these lesions.

It is beyond our purpose even to mention all the dusts of mineral, vegetable, or animal origin that may penetrate the air-passages; however, it is, perhaps, not without interest, from a pharmacologic standpoint, to study their **method of penetration** and the **path** by which they enter the organism. The powdered dust cannot enter the parenchyma where the bronchial mucous membrane is intact and covered with ciliated epithelium; it is arrested here by the mucus and directed by the action of the cilia toward the larynx, where it is expelled by coughing. Rindfleisch opened wide the mouth of a frog and threw a quantity of carbon-dust upon the mucous membrane of the palate, which is covered by ciliated epithelium in this animal; with the naked eye one could see the slow forward movement of the black masses. This explains one's black expectoration the day after a prolonged consumption of the midnight oil, or after a long railroad trip. In order that absorption of these particles may take place in the bronchi, a lesion of the mucous membrane must exist, causing diminution or even suppression of the physiologic function of the epithelial lining; this lesion may occur from the frequent repetition of the action of the dust, or if the exposure be short, when the dust is in great abundance. If a bronchial lesion were necessary for absorption in every instance, the inhalation of powders, particularly of insoluble agents, would have to be condemned at once as a method utterly impossible of effect upon the lung or the system. Absorption of solid particles, however, is

possible without the existence of an antecedent lesion, but the effect occurs directly in the alveoli; here there is no secretion of mucus, no cilia to throw off foreign bodies. The particles are to be found free or inclosed in the epithelial cells, and, especially, in the leucocytes; after remaining in the alveoli a certain length of time they penetrate the parenchyma. The leucocytes, according to Carrière, are the intermediaries in this migration; arriving by diapedesis in the alveoli, they there absorb these foreign substances in accordance with their phagocytic function; they then enter the perialveolar lymphatic circulation—where they can be seen under the microscope—and by this channel arrive at the bronchial glands. If the particles are very finely divided, they escape through the glands, but not so if they are numerous. The glands become inflamed and impermeable; whatever else may be the cause of the impermeability, once developed, it becomes the starting-point of a pneumoconiosis. These data result from microscopic examinations. The lung of an old person examined with a magnifying glass shows, besides lines and streaks, black in color, indicating the outlines of the lobules, fine ramifications penetrating into the lobules as far as the walls of the infundibulæ. Anatomically these lines correspond to the distribution of the lymphatic vessels.

The studies just cited refer particularly to carbon-dust; the same anatomic and pathologic conditions, however, affect and result from the inhalation of other powders. The absorption of silica (chalicosis) may be said to be physiologic, for while it does not occur in children's lungs, evidences of it are always found in adults; it becomes pathologic when excessive, as among certain artisans,—stone-cutters, grinders, workers in porcelain, crockery, and the like. These lesions have been studied by Meinel, Lemaistre, Pâté, and others. Zenker has described very accurately the infiltrations of ferruginous particles in the lungs in cases of siderosis. The lungs of a woman thirty-one years old, who had worked in a small room, using the red oxid of iron in powder upon sheets of transparent paper, were examined. They exhibited a uniform intense brick-red color, with darker lines indicating the contour of the lobules; Gorup-Besancz demonstrated chemically the presence of the iron salt. Similar observations have frequently been made in a considerable number of cases.

Experimental Proof

It would seem superfluous after the above anatomic proofs to seek to establish by experimental evidence the penetration of particles of dust into the lung; yet certain additional facts are necessary to

complete our study. Accepting anthracosis of the lung as proved, certain authors have asserted the possibility of the entrance of the carbon particles through the wall of the intestine, and indeed Osterlein, Mensonides, and Donders, Orfila, Charles Robin, and Villaret have established experimentally that ingested carbon particles may thus reach the lung. But after all, is this the usual way (Charcot)? The experiments of Fournié (1863), of Rosenthal (1865), and those of Knauff, Charcot, Feltz, and others have answered this query. Knauff placed dogs in an atmosphere rendered smoky by a lamp; at the end of several hours the animals were killed and the lesions found were solely those of anthracosis,—pigmentation of the lungs, pleuræ, and bronchial glands. Charcot experimented with guinea-pigs which he placed in sacs impregnated with coal-dust or with red oxid of iron; he was able to recover the carbon and ferruginous particles inclosed in the epithelial cells of the lungs. Feltz caused very finely pulverized coal particles to enter the air-passages of rabbits under varying conditions, and found at the points of irritation caused by the dust, either a simple proliferation of the epithelial cells or a purulent degeneration of the epithelium of the bronchial tubes. These experiments show that anthracosis follows rapidly when the animal is obliged to breathe through the mouth. Further, Balzer, in support of this view, showed that after tracheotomy the lungs become pigmented in a few days. Before leaving this subject, it may be added that Hanau has demonstrated the tendency, in cases in which the particles are not abundant, for the apex of the lung to be infiltrated; when, on the contrary, they are abundant, the bronchial mucus, following the laws of gravity, carries them toward the base.

From this rather extensive review we may draw certain appropriate **conclusions.**

The introduction of **insoluble powders,** or powders incapable of being made soluble for purposes of inhalation has been demonstrated upon anatomico-pathologic grounds to be **dangerous** in the long run: (1) because it can only cause irritation and alteration of the bronchial epithelium if the applications are too frequent or too abundant; (2) if the doses are small and infrequent, the production of mucus, and the movements of the ciliated cells tend to drive these substances out of the air-passages; and (3), what is of greatest importance, a certain quantity may reach the alveoli and thence pass into the lymphatic system, where the presence of these foreign bodies may cause more or less grave and persistent lesions. When the mucosa is altered, the insoluble particles may penetrate the walls of the bronchi. However, it does not follow that

we are to reject absolutely the use of insoluble powders; but that they ought to be applied by aspiration through the nose, or by direct insufflation into the throat or larynx; the end to be attained being to cover the inflamed or ulcerated mucosa with an insulating application, a sort of dressing, sheltering it from the irritating secretions.

Among powders capable of becoming soluble are a number that in the presence of the secretions undergo a chemical alteration permitting their absorption; of these, certain MINERAL SALTS and IODOFORM deserve prominent mention. Substances of this class are most frequently employed. It must be remembered that in cases in which it is desired to reach the bronchi or lungs the patients ought to breathe through the mouth; that, as a rule, the breathing of these powdered substances being very irritating, the sessions should be of short duration and repeated at sufficiently long intervals; and, finally, that absorption is rapid, and care must be taken to avoid poisoning.

Insufflation

It is difficult to separate sharply the inhalation of powders from the closely allied method of **insufflation**; we are therefore led to say a few words concerning the latter.

For the **nasal mucous membrane,** our previous recapitulation of the experiments of Paulsen, Aschenbrandt, and Block should suffice. Nasal respiration, in a powder-laden atmosphere, allows of the entrance of only a small quantity of dust into the nasal chambers, especially if the quantity of dust in the air is not excessive. The vibrissæ and the secretion of mucus tend to prevent the entrance of solid particles. Therefore, snuff-takers are obliged to put a rather large quantity of the agent into the nose itself, and to inhale it strongly.

METHODS AND INSTRUMENTS

Apparatus for Inspiration of Powders

In most of the methods praised by writers it is certain that the greater part of the medicament does not pass the pharynx and that only a small amount reaches the larynx. I shall mention only those in which with care and skill success is possible.

For inhalation of powders, Erasmus Darwin (1790) suggested a small box with two openings, one furnished with a mouth-piece, the other allowing access to the atmosphere. The powder was placed in the box and stirred up by means of a revolving brush operated by a hand-crank, or by clock-work. Neidermayer's instrument substituted

a sort of leathern paddle-wheel for the brush of Darwin. Trousseau and Belloc advised the use of a glass tube of suitable dimensions: at one end about 15 to 25 centigrams (say 3 to 5 grains) of the powder are introduced; the other end is inserted as deeply as possible into the mouth of the patient, who closes his lips upon the tube and takes a deep inspiration. In some cases, however, the powder is expelled by the expiration or becomes moist. In order to avoid these accidents, Burow made use of two parallel tubes; one is empty; the other, in which the powder is to be placed, is fitted with a valve that opens only at the moment of inspiration and closes with expiration. Ebert directed the patient to close his nostrils, and to take a sudden deep breath; the first inspirations of powder scarcely pass the base of the tongue, but within a short time the patient can manage to make it reach the larynx. Lewin and Oertel made use of an apparatus patterned after that of Darwin.

FIG. 113.—POWDER INHALER OR INSUFFLATOR WITH INTERCHANGEABLE TUBES.

It consists of a sort of horn furnished with an opening; through this penetrates a glass tube, to the outer portion of which is attached a rubber bulb; gentle manipulation of the bulb produces in the horn a thick cloud of dust, which is propelled toward the narrow end of the instrument, where it is directly breathed by the patient. In the United States there is sold an instrument (Fig. 113) to be used either with a hand-bulb or a current of compressed air from a reservoir. A glass vessel is closed by a metallic cup carrying two tubes; one, for the air-current, is furnished with a simple valve and passes below the surface of the powder, with which the container is filled to about one-third of its capacity; the other partly passes through the cap and terminates in a suitably shaped application tube; the instrument being furnished with a number of interchangeable terminals. It may also be used for insufflation.

Dean's Modification of the Stormer Norwegian Inhaler.—This consists of a heater, partly of metal and partly of glass, so constructed that air can be admitted at the base, heated, and discharged at the upper orifice. Into this heated current of air a fine spray is thrown from an atomizer, through an opening provided for the purpose. The spray is immediately vaporized; if the active agent is a liquid, it will be inhaled as vapor; if a solution of a solid, it will be crystallized and inhaled as a dry powder; in either case issuing in an invisible condition. The apparatus was originally intended for the administration of SILVER NITRATE; but various other medicines, such as IODOFORM, PHENOL, PHENOL-CAMPHOR, IODIN, have also been used with good results. That the impregnated air when respired reaches the fine bronchial tubes has been proved by experiments on animals; inhalations of a mercurial salt have produced ptyalism; traces of potassium iodid have been found in the urine; and terpinal and santal give to the urine the characteristic odor of the violet, and have been found to modify catarrhal conditions of the bladder.

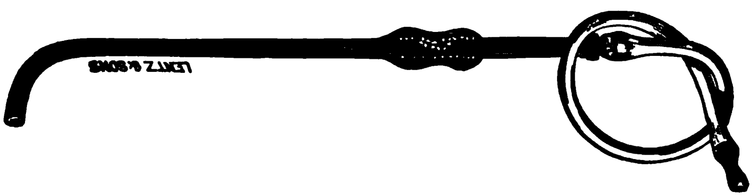

FIG. 114.—LARYNGEAL INSUFFLATOR WITH MOUTH-TUBE.

Insufflators

Most of the insufflators recommended are of the Rauchfuss-Gilewski pattern. Stoerk at first used a mouth-tube, the physician using his own breath to perform insufflation; Czermack substituted a rubber bulb. The ordinary apparatus is composed of such a bulb attached above or to the end of a tube, at the upper portion of which is a small opening for the introduction of the medicating powder; a mechanism of some sort, generally a concentric ring, sliding over the tube, effects the closure of the orifice. In other instruments a small glass or hard-rubber receptacle contains the powder. Different tips for different purposes may be attached, for use on the nose, throat, larynx, etc.

Bryant has proposed the use of an **auto-insufflator,** consisting of a bent tube, having at one point an opening, which may be closed by a stopper. Through this opening the powder is introduced; one

end is placed in the nose, the other in the mouth, and gentle blowing is performed. A simple rubber tube answers the same purpose. For insufflation into the larynx and trachea one uses special curved instruments. (Figs. 114, 115.) For insufflation into the pharynx and upon the tonsils any tube may be employed, such as a reed, quill, glass or rubber tube, or a special instrument (Fig. 116).

PHARMACOLOGY

ALUM, recommended by Laennec, Pommier, Bretonneau, in **diphtheria** and most **throat affections,** has been almost entirely discarded; it should be used in small quantities, mixed with one, two, or three parts of sugar of milk. I have often seen veritable burns in patients who had been insufflating themselves with alum.

TANNIN is certainly more commendable; it is usually combined with CAMPHOR, BORAX, etc., and is used in **coryza,** and **ozena,** and some authors even consider it capable of destroying, or preventing the return of, **mucous polypi** by a peculiar effect upon the mucous mem-

FIG. 115.—INSUFFLATOR WITH HAND-BULB.

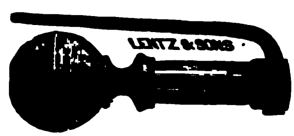

FIG. 116.—FOLDING INSUFFLATOR WITH GLASS BARREL.

brane (Waldenburg, Bryant). That, however, is a procedure not to be recommended to-day, and one which usually is a complete failure.

LEAD ACETATE, 1 part to 5 or 6 of sugar of milk for **chronic coryza with** abundant secretions, ZINC SULPHATE, IRON SULPHATE (1 to 20) with sugar of milk, for **chronic coryza, polypi,** etc., have been abandoned.

The treatment of **diphtheria** by insufflation of SULPHUR (Barbosa, Lutz) merely merits mention.

CALOMEL, 1 to 12 of sugar of milk, RED MERCURIC OXID, 1 to 36, have been used with success in **ulcerous affections of the throat,** particularly those of **syphilitic** origin (Trousseau, Waldenburg).

SILVER NITRATE, of all drugs, has, perhaps, been most frequently and most highly praised. Trousseau prescribed it in a mixture with 25 [illegible] 70 parts of the sugar of milk. Waldenburg with 5 to 25 parts of [illegible]ned alum, Bruns in one-sixth strength with talcum. Thomas [illegible]ated a silver nitrate solution with lycopodium and then reduced

this to an impalpable powder. This drug has been used in **coryza** (Barbier), **ulcerations of the pharynx and larynx** (Trousseau), **chronic laryngitis** (Burow, Ebert), and **gangrene of the lung** (Pserhofer).

The **sedatives** have also been employed frequently. Gueneau de Mussy has recommended MORPHIN by nasal insufflation, in the treatment of **facial neuralgia,** but it is especially in **dysphagia,** particularly if due to **tuberculous laryngitis, cancer,** or **syphilis,** that one resorts to its use. Nowadays COCAIN and MENTHOL have to a large extent displaced it. A combination of ORTHOFORM or ANESTHESIN with desiccated and pulverized SUPRARENAL SUBSTANCE is often of service in the presence of tuberculous and other **painful ulcerations.**

With these we must group most of the antiseptic substances: CAMPHOR, BENZOIN IN POWDER, SALICYLIC ACID (Ludlow), BISMUTH SUBNITRATE (Trousseau), SODIUM BORATE, BORIC ACID, SALOL, IODOFORM, IODOL, ARISTOL, EUROPHEN, NOSOPHEN, XEROFORM.

General Indications.—It would appear worth while, before closing the question of the inhalation of powders, to give a résumé of the actual possibilities of the treatment, and to mention a few of the **formulas** selected from among those I have had occasion to test. I do not pretend to give all the formulas that have been highly praised during the last fifty years. I shall limit myself to those in current use.

In affections of the **trachea, bronchi** and **lungs,** my experience scarcely warrants a decision. Over and over again I have tried the inhalation of powders of iodoform, iodol, and aristol; I have used the following in accordance with theoretic deductions not necessary to go into here: 1 gram of IODOFORM is dissolved in 50 to 100 grams of ETHER, and with this mixture 100 grams of dried BREWER'S YEAST are moistened. This is carefully mixed, the yeast is dried, and after being finely powdered it is applied through an apparatus similar to those of Darwin and of Lewin, which have been described. I have prescribed this in cases of **tuberculosis** only; it suffices to say that the results have appeared satisfactory; I should not be warranted in saying more.

In **laryngeal affections** I have made applications with the apparatus of Rauchfuss, and in a number of cases with success. The two especial indications are **ulceration** and **pain.** Again, it is in **tuberculous** cases for the most part that I have resorted to this method. The **formulas** employed have been numerous. Long ago I discarded the use of the so-called astringents—mixtures of sugar of milk or starch with

tannin, alum, and lead acetate. IODOFORM, when well tolerated, is one of the best topical applications; in some cases ARISTOL, IODOL or DIIODOFORM is substituted for it. COCAIN can always be combined with iodoform, but its analgesic effect is brief, and where prolonged effect is desired, either MORPHIN, ANTIPYRIN, MENTHOL or ORTHOFORM is added. The last-mentioned appears to me to have an uncertain action.

Here is a convenient formula:

Powdered sugar of milk,	0.10 (1½ grains)
Iodoform,	0.02 (⅓ grain)
Cocain hydrochlorate,	0.01 (⅙ grain)
Menthol,	0.01 (⅙ grain)

For one insufflation.

In pharyngeal ulcerations I have found SALICYLIC ACID very effective; MENTHOL is, however, the most valuable analgesic:

Salicylic acid,	0.25 (4 grains)
Menthol,	0.25 (4 grains)
Quinin hydrochlorate,	0.10 (1½ grains)
Powdered boric acid,	20.00 (5 drams)

Four or five grams (about one dram) is used at each insufflation. In cancerous cases MORPHIN is added, 5 to 10 milligrams ($\frac{1}{12}$ to $\frac{1}{6}$ grain) for each insufflation.

For **nasal affections** SNUFFS, a special form of nasal insufflation, are indicated.

My basic formula is:

Powdered boric acid,	20.00 (5 drams)
Salol,	1.00 (15 grains)
Menthol,	0.50 (7½ grains)

SALOL sometimes causes, exceptionally however, folliculitis of the vestibule.

When there are hemorrhagic erosions of the septum, I add 1 to 5 grams (15 to 75 grains) of ANTIPYRIN. This last drug causes in certain patients, and rather often too, herpetic eruption.

In **vasomotor rhinitis** I add a small dose of COCAIN, 0.10 to 0.20 gram (1½ to 3 grains), and 2 grams (30 grains) of QUININ SULPHATE. In this affection ADRENAL SUBSTANCE is highly useful (S. Solis Cohen) and it may be added to the snuffs. Usually, however, a solution, either of the adrenal substance or of its active principle (adrenalin chlorid, 1 : 4000), used as a spray, or on a pledget of cotton, is to be preferred.

SODIUM SOZOIODATE (Bresgen) is useful, especially in the **chronic rhinitis of children**; Schech prefers the ZINC SOZOIODATE.

Gottstein recommends the following prescription in **chronic non-hypertrophic rhinitis:**

Salicylic acid, ...	1.0 (15 grains)
Calcined magnesia, ...	10.0 (2½ drams)

I have obtained results with it in the mild cases only. SILVER NITRATE, 0.05 to 10 grams of powdered starch (1 grain to 2 drams), has succeeded better in more obstinate cases: I make these applications every two or three days, to one side only at a time, and increase the strength according to the tolerance, and the intensity of the local reaction.

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